AMRL-TR-76-34

USING COMPUTER-GENERATED DISPLAYS FOR RESEARCH ON SYNTHESIZED DISPLAYS: DISTANCE PERCEPTION AIDED BY AERIAL PERSPECTIVE AND TEXTURE

HUMAN FACTORS ENGINEERING
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AEROSPACE MEDICAL DIVISION
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AMRL-TR-76-34

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FOR THE COMMANDER

CHARLES BATES, JR.
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Human Engineering Division
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This report relates to an evolving capability to faithfully duplicate real world scenes on cathode ray tubes on the basis of numerical models and data stored and processed by digital computers. The potential accuracy and detail of such "computer-generated imagery" are virtually unlimited assuming appropriate computational power and software are provided. The research described is part of an effort to develop a basis for assuring that future computer-generated display features are consistent with cost and user information requirements.

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20. (continued)

Experienced air crew members and university students estimated distances on the basis of quantitatively defined visual cues included in computer-generated displays. Estimates were obtained for eight different distances depicted by variations in the position and size of an object of specified dimensions. The object was rectangular in shape, blue in color, and appeared on a green background. The distances represented were 3,000; 5,000; 8,000; 12,000; 17,000; 23,000; 30,000; and 38,000 feet.

Two additional features of the computer-generated displays were investigated as independent variables: (1) aerial perspective at four levels of visibility, or fog, and (2) background texture. The background texture was produced by stripes of different shades of green overlaid at right angles to form a random pattern. Three levels of texture were generated by depicting stripes 1000, 2000, and 4000 feet in width.

Decreases in visibility resulted in significant increases in distance estimates for the three greatest distances. However, air crew members effectively compensated for the visibility effect on their second trial; students did not. Both groups of subjects tended to overestimate under all conditions; students did so more than air crew members. Estimates by students were significantly more accurate when background texture was added.

SUMMARY

1. Students and air crew members were asked to estimate the distance to one of several buildings within a computer generated pictorial display as a function of the level of aerial perspective factor or the size of a background texture gradient.

2. Aerial perspective factor was used as a cue to distance by student observers, but not by air crew members. Increasing levels of APF produced increasing distance estimates for the farthest three buildings.

3. Addition of a textured background reduced the large over-estimation of distances by students found in the first experiment. The no-texture control condition produced the largest estimates by air crew members, while the 1000 ft. condition produced the largest estimates for the students. Again, the effects were most clearly seen on the farthest three buildings.

4. In the second experiment subjects responded as though the buildings were equally spaced horizontally at distances of 1 to 8 miles. It was not clear whether the display appeared this way, or whether this was a response strategy.

5. Both groups of subjects over-estimated the distances to all buildings in both studies. Possible reasons for this are the visual angle of the display, the unusual altitude (students), incorrect assumed size of the buildings, lack of sufficient cues.

6. The response variability was less among air crew members than students, presumably due to a higher motivation for accuracy.

7. Areas for future study include the visual angle of the viewing screen in relation to the size of visual angle of the display, the altitude of the observation point, motion within the display or the addition of other objects for more relative size cues.

PREFACE

This report has been prepared as a part of the effort under contract F33615-75-C-5146 between Wright State University and the Aerospace Medical Research Laboratory. Dr. Malcolm L. Ritchie is Principal Investigator for the University and Billy M. Crawford is contract monitor for the Air Force.

The authors wish to acknowledge the assistance of Patricia Vendt and William Marras in the conduct and analysis of the experiments described.

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INTRODUCTION

Recent advances in computer processing and cathode ray tube displays have widened the field of information display considerably. The combination of computers and cathode ray tubes allows an almost limitless variety of colors and shapes to be displayed in three dimensional space with accurate position and perspective cues. With this broadening of display possibilities and their inherent costs, it becomes necessary to investigate which features are consistent with cost and the information requirements of the users.

The two experiments reported here were designed to investigate perceptual variables involved in the design of complex computer generated displays. Both experiments involve pictorial rather than symbolic displays; in particular, the perception of depth or distance within a pictorial display. Although the picture displayed by the computer depicts three dimensional space, the cues available to an observer are the pictorial or monocular cues such as linear perspective, aerial perspective, relative size, texture and height in the field.

In the first experiment we asked subjects to estimate the distance, in miles, to one of several buildings within a landscape. The building was presented on a plain green background. The only cues to the distance were relative size, height in the field, and the level of Aerial Perspective Factor (APF). Aerial perspective is defined as a fog or haze which increasingly desaturates colors and blurs the details of objects seen at increasing distances. Without any Aerial Perspective Factor in a simulated landscape there is a cartoon-like quality to the display and pilots observe that the horizon looks "too high." We used three levels of Aerial Perspective Factor and one stimulus series with no APF. The results suggest that the naive student observers use the APF as a cue, but experienced air crew members do not.

In the second experiment we again asked subjects to estimate the distance to a building within the display. The buildings were presented on one of four backgrounds, three of which were composed of different sizes of "blocks" to create three different sized texture gradients. The fourth background was the plain green used in the first experiment. Reports by Gibson (1950a; 1950b) and Braunstein (1968) have described the importance of the texture gradient to the perception of depth or slant of a surface. Wohlwill (1962) has investigated the effect of different textured backgrounds on relative distance estimations. In this experiment we determined the effect of different sizes of textured backgrounds on the estimation

of absolute distances. The results showed a difference in distance estimates as a function of texture size which, although statistically significant, was not obvious from the figures. In addition, the texture produced a large improvement over the first experiment in the accuracy of estimates by naive observers.

The results of the experiments are discussed in terms of the relative importance of various perceptual cues to the estimation of distance within the complex computer generated display.

EXPERIMENT I

Aerial Perspective Factor

Subjects

Subjects were 20 experimentally naive students in the Introductory Psychology class at Wright State University. They were between the ages of 18 and 25 and had no previous piloting or skyjumping experience. All subjects had 20-20 vision and unimpaired color vision.

In addition, 10 air crew members (predominantly pilots) from Wright-Patterson AFB volunteered to participate for purposes of comparison with the students.

None of the students or air crew members were informed of the purpose of the experiment until the conclusion of the session, when all subjects were thoroughly debriefed. Participation by both groups was voluntary.

Stimulus Display

Apparatus. The stimulus display consisted of a series of computer generated images recorded on videotape with a Sony video-cassette recorder and replayed through an Advent Projection System (Model 1000A, Advent Corporation, Cambridge, Mass.).

The Advent Projection System consists of a 4.5 x 5.5 ft. projection screen and three projection tubes. The peak wavelengths of the three phosphor tubes were 600 nm (red), 525 nm (green) and 435 nm (blue). The focus and convergence of the three beams were checked before each experimental session and corrected if necessary.

The Advent Projection System operates from an external source with 525 scanning lines interlaced 2:1 with the 60 Hz field rate and the 30 Hz frame rate. The resolution of the system is determined by the NTSC video bandwidth and is not limited by the electron optics, projection lens system, or by the segmentation of the raster into color dots or stripes. The horizontal resolution of the Sony Video-Cassette Recorder (Model V-1800), which was used for recording and playback of the cassettes, is 230 lines.

The visual angle subtended by the viewing screen was 18°30' by 22°30'. Subjects were seated 14 feet from the screen, the minimum distance suggested by the Advent Corporation for good viewing.

The stimulus display tapes were produced by General Electric Company of Daytona Beach, Florida. The generation of the display requires a special purpose display generating computer and a second computer for modeling or programming the display. Numbers are fed into the programming computer that represent points in space and can be connected to form lines, surfaces and three-dimensional objects. The objects so formed can be located anywhere within a 200 mile cube with an accuracy, for each point, of one foot. The display is produced in full color using the techniques of color television. Objects must be constructed of straight lines and, due to the limited capacity of the display computer, the complexity of the display is limited to that which can be produced with 500 lines or edges.

The computer's viewing point is also precisely specified, and all objects are shown in true linear perspective from that single point. The display is recomputed 30 times per second, allowing for full motion capability. The viewpoint can also remain fixed, as was done in this experiment.

Stimuli. The stimulus images consisted of landscapes generated by the computer in the manner described above. The landscapes were depicted with the viewing point 1000 ft. above the ground. The visual angle displayed was 72° horizontally and 60° vertically.

Within each stimulus landscape were presented two "buildings" 100 ft. high, 300 ft. long, and 10 ft. deep. One building, the standard, was always presented in the center foreground at a known distance of 0.4 mi. (2000 ft.). The second building, the comparison, was presented directly behind the standard at one of eight distances as follows:

0.56 mi. or 3,000 ft.
0.94 mi. or 5,000 ft.
1.60 mi. or 8,000 ft.
2.20 mi. or 12,000 ft.
3.20 mi. or 17,000 ft.
4.30 mi. or 23,000 ft.
5.60 mi. or 30,000 ft.
7.10 mi. or 38,000 ft.

for a total of eight pairs of buildings. The size and linear perspective of the buildings were as accurate as possible for the viewing distance and altitude, given a finite width for the raster lines and elements. Thus, the two farthest buildings both consisted of a single raster line and differed only in width, or the number of horizontal elements.

The buildings were presented on a solid green background. The buildings were deep blue and the sky was light blue. The luminance of the green background was approximately 3 foot-Lamberts, the sky, 7.7 foot-Lamberts and the buildings, 2 foot-Lamberts. The addition of APF did not have a significant effect on the luminance of the screen.

Each stimulus frame also contained one of four levels of Aerial Perspective Factor The APF can be described as a fog or haze that increasingly blurs the horizon, desaturates colors and obscures details of objects presented at increasing distances within the display. The color of all objects changes from their assigned tones towards the fog tone as a function of distance through the fog between the observer and the object. For normal fog, the "function of distance" is a negative exponential, $F = e^{-kd}$ where d is slant range to the object, k is an attenuation coefficient, and F is the range factor. In computing Aerial Perspective Factor, the density of the fog decreases with increasing altitude. The slant range d is specified as $d = d' + 10h$ where h is the altitude of the viewing point or 1000 ft. Thus, in this experiment d' was specified as 0, 8000, or 32,000 ft. + 10h. The slant ranges at which the buildings were 50% assigned tones and 50% fog color were, therefore, 10,000 ft., 18,000 ft., 42,000 ft., and infinity (no APF). The color of the fog consisted of equal amounts of red, green and blue. For a further explanation of how the color of objects within a fog is determined see the Appendix.

Each stimulus pair (the standard and one of eight comparison buildings) was displayed with each level of APF for a total of 32 stimulus conditions. The stimuli were presented in randomized order for 20 seconds each with 10 seconds between stimulus frames. This sequence was reversed for the second run.

Subjects were also shown a sample videotape of a simulated runway landing, as a "warm-up" to acquaint them with computer generated imagery. The background hues were similar to those used in the experimental tape. However, there was some ground texture, the visibility factor was 16,000 ft., and the "plane" was in motion.

The room lighting was extinguished and ambient light was minimized in order to reduce uneven illumination of the viewing screen.

Procedure

The Advent Projection System was turned on at least one half hour before the session to minimize hue or convergence shifts during the experiment.

The focus and convergence of the Advent Projection System were checked and corrected before the start of each experimental session. Brightness, contrast, and tint were not adjusted, once an acceptable image was obtained during the initial adjustments of the system.

Each male subject (both students and air crew members) was tested for normal color vision using the Dvorine pseudoisochromatic plates.

Subjects were seated behind the projection system with a forehead and chinrest to maintain a steady head position.

Subjects were first informed that they were about to view a computer simulated runway landing. They were told that the runway was about a mile long, and that the purpose of the tape was to familiarize them with a computer generated display. The warm-up tape was then shown.

Following the warm-up tape, subjects were informed that the experimental tape was generated in a similar manner, however the distances of the objects within the display might not be the same as in the previous display. They were told that all buildings within the display would be the same size - 300 ft. long and 100 ft. high - and that the first building was always 0.4 miles away from them. They were also told that they were 1000 ft. above the ground. Given this information they were instructed to estimate the apparent distance to the second building in miles or fractions of miles to the nearest 1/4 mile.

Subjects were shown two different randomized sequences of the stimuli. The second sequence was the reverse of the first.

The subjects' responses were recorded for subsequent analysis by the experimenter who was seated in the experimental room.

Results

The results of Experiment I, Aerial Perspective Factor, indicate that increasing the amount of APF increases the estimated distance of objects within a complex display for naive subjects, but not for experienced pilots.

Student Subjects

The means of the raw score distance estimates for the eight buildings at each of the four APF levels are presented in Figures 1-3. Figure 1 shows the results for the first sequence. The circled points indicate the subjects' first five responses. Figure 2 shows the results for the second, reversed sequence, and Figure 3 represents the average of the two sequences. Several facts are clear from the figures.

1. Naive subjects significantly over-estimate the distances to all the buildings.
2. The over-estimations in the second sequence are greater for the shorter distances (a factor of 5.5 to 10) than for the longer distances (a factor of 4.6 to 7). As can be seen in Figure 4, except for the first, or closest, building (0.56 mi.) there is no overlap between the distribution of the relative over-estimation of distance to buildings 1-4 and that of buildings 5-8. In order for the relative over-estimation to remain constant, the actual error must be increasing with distance.
3. The Aerial Perspective Factor (APF) has a significant effect on the estimates for the last three buildings and little or no effect on the estimates for the nearer buildings.
4. The largest difference between APF levels is between the ∞ or no APF condition and the three lower visibility levels. Differences between the three lower visibility levels tend to be smaller.
5. The effect of APF is to increase the estimated distance to the more distant buildings.
6. A comparison of Figures 1 and 2 indicates that naive subjects tend to increase their distance estimates in the second sequence over the first.

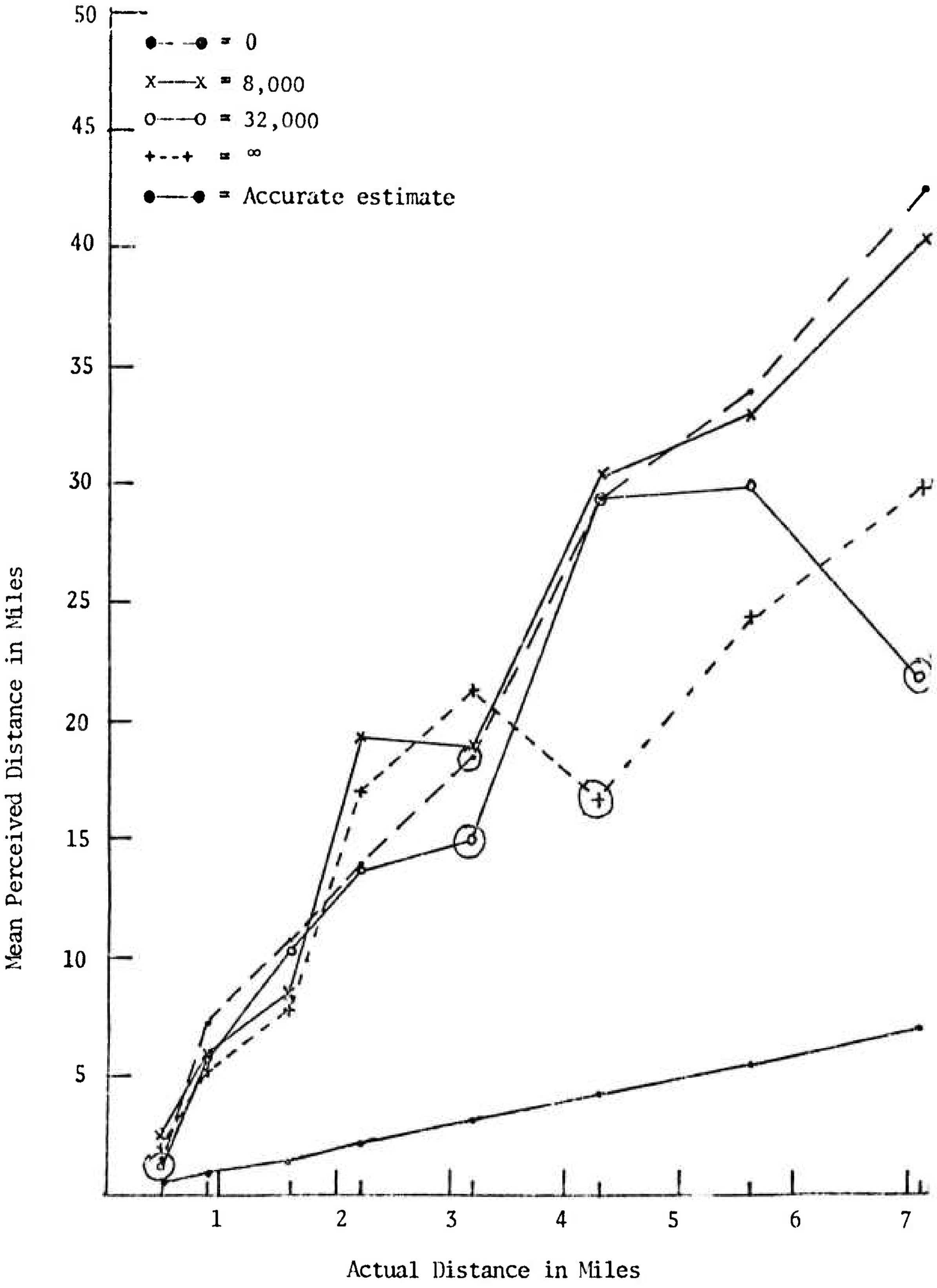

Figure 1. Raw score data for first run. Student observers. Circled points indicate first five estimates by the subject.

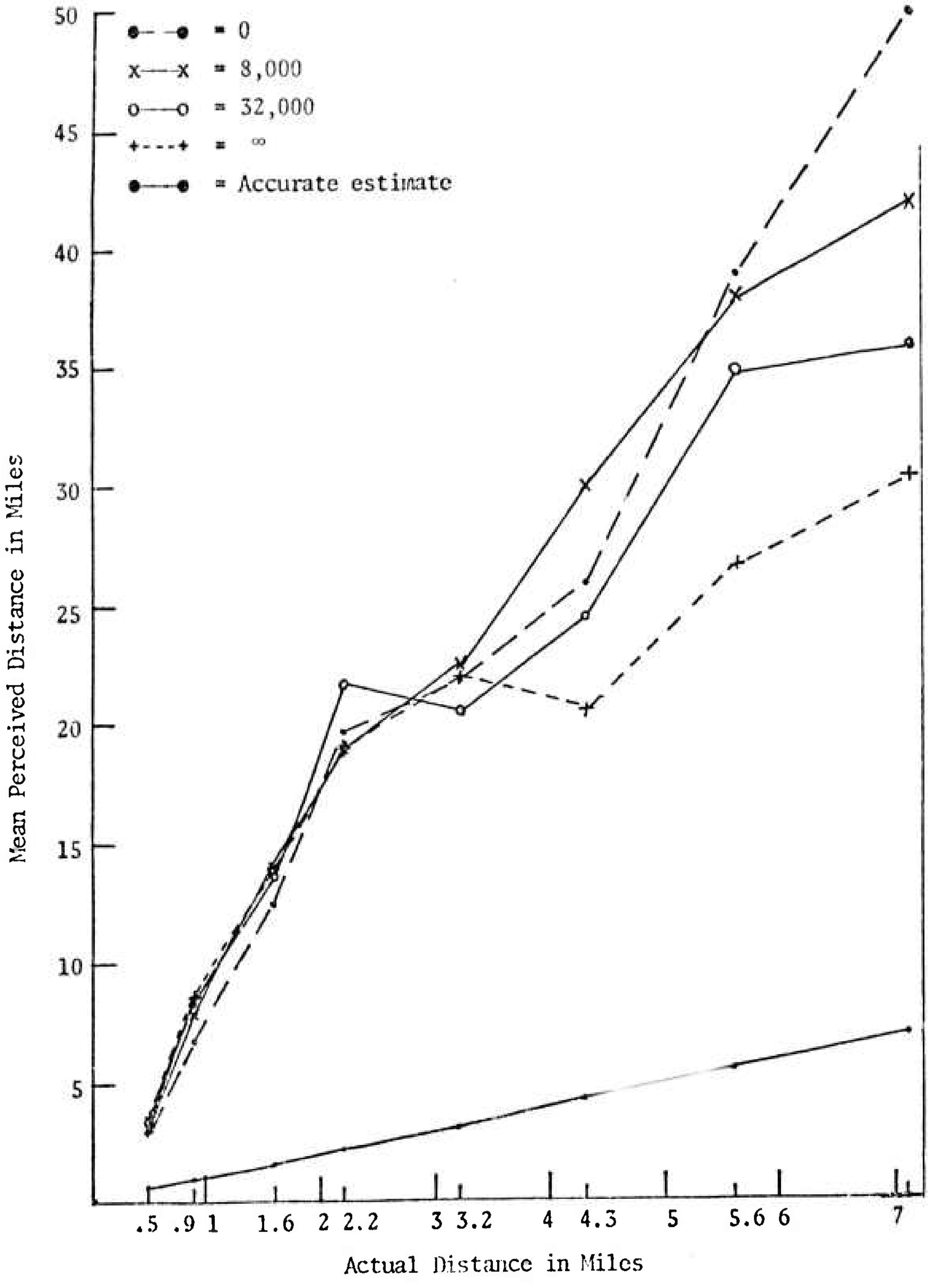

Figure 2. Raw score data for second run; reverse order from Figure 1. Student observers.

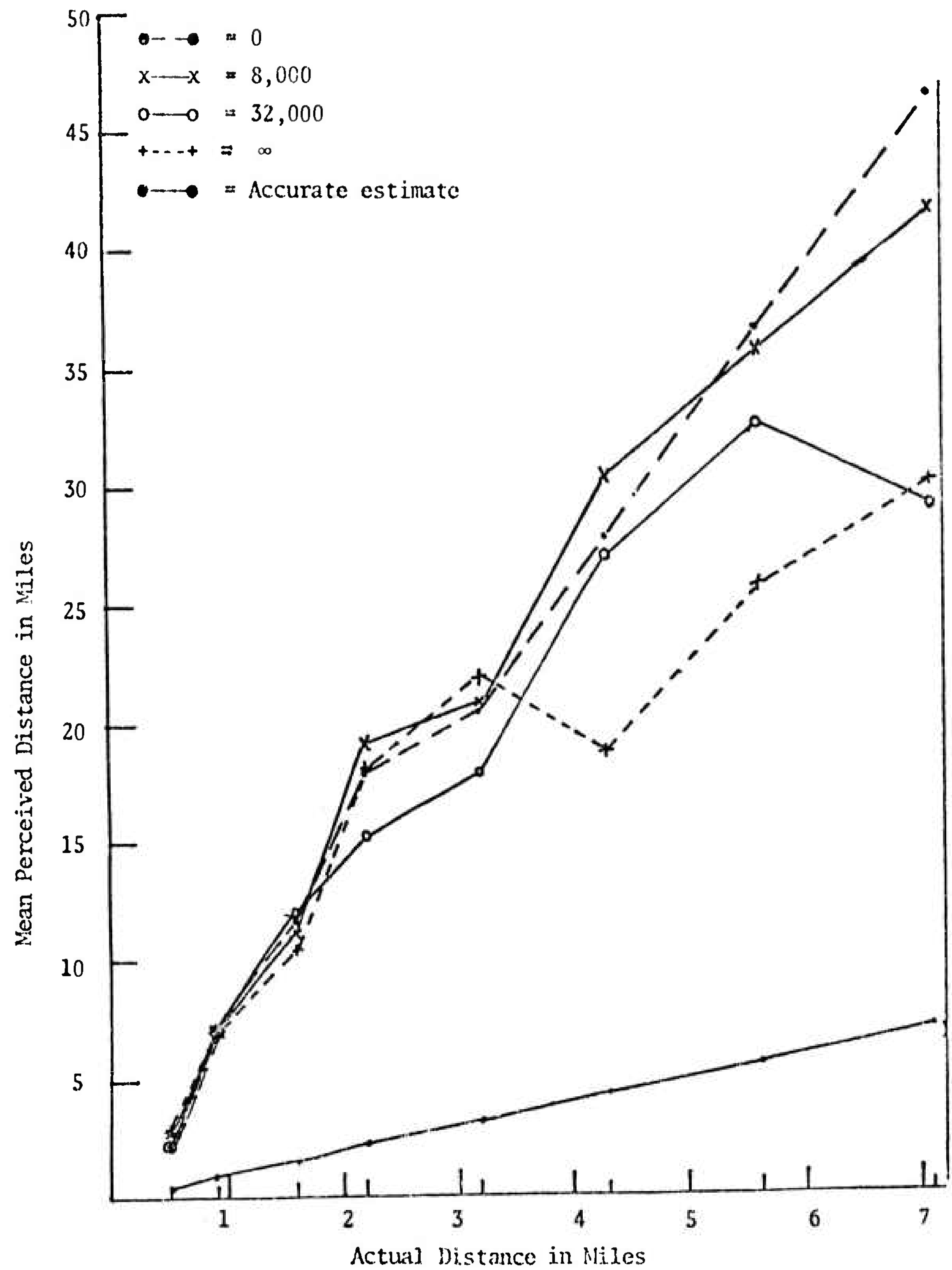

Figure 3. Mean of raw score data from Figure 1 and Figure 2. Student observers.

7. In the first sequence the first five estimates tended to be shorter than subsequent estimates of distance to the same buildings.

An analysis of variance was performed on the distance estimates of the naive subjects. The source table is presented in Table 1. Alpha was taken as 0.05. There is a significant difference between the building distance estimates, which was expected, ($p < 0.001$). There is also a significant difference between the visibility (APF) levels, ($p < 0.001$). As there was no significant difference between the results for the two sequences ($p = 0.72$), the data were combined for further analysis. Table 2 presents the means and standard deviations for both sequences.

The distances to the middle buildings (2-5) were over-estimated more frequently and to a greater extent than any of the others. Subjects' responses indicated that they were sometimes confused as to which building they were observing. This confusion was not apparent for the first and the last two buildings. With the scarcity of position cues, subjects appeared to be influenced to a large extent by their response to the previous stimulus. Middle buildings that appeared after more distant buildings were judged as being closer than those that appeared following the closer buildings. Thus, the buildings at 0.94, 1.6, 2.2, 3.2, and 4.3 miles tended to be judged more on a relative scale where the standard became the previous stimulus rather than the presented standard or the horizon.

Considering Fig. 4; one might ask if students were performing the same task in estimating the distance to the first four and last four buildings. The reason for this dichotomy is not apparent from the data, nor were subjects' comments at all enlightening. There is a change in inter-building distance at this point (from $\sim$ 0.5 mi. to $\sim$ 1.0 mi.). However, the average perceived distance between each of the comparison buildings was:

4.5 mi. between buildings 1 and 2 (0.56 and 0.94 mi.),
5.6 mi. between buildings 2 and 3 (0.94 and 1.6 mi.),
6.3 mi. between buildings 3 and 4 (1.6 and 2.2 mi.),
2.0 mi. between buildings 4 and 5 (2.2 and 3.2 mi.),
3.5 mi. between buildings 5 and 6 (3.2 and 4.3 mi.),
9.3 mi. between buildings 6 and 7 (4.3 and 5.6 mi.),
and 5.0 mi. between buildings 7 and 8 (5.6 and 7.1 mi.).

Thus, there is no direct relation between the actual distances and the perceived distances between comparison stimuli. There does not appear to be an effort to maintain equal distances between buildings. The differences are almost random.

Figure 5 presents the logarithmic transformation of the means of the distance estimates. The logarithmic transform was performed in an effort to reduce the non-homogeneity of variance (see Table 1) (Winer, 1962, p. 219). By translating the position of the curve representing the logarithm of the true distance upward, one can see that the estimated distance curves differ from the true distance curve mainly at the middle distances. The estimates for the first and last buildings in the 32,000 ft. condition can be matched to the true curve, but the middle distances are relatively overestimated. An analysis of variance using the transformed scores yielded results similar to those in Table 1. The source table is presented in

Table 3. The logarithms of the means and standard deviations are presented in Table 4.

Figure 6 presents the relative transformation of the distance estimates. Each of the estimated distances for each sequence is displayed as a ratio of that estimate to the estimate of the distance to the farthest building (7.1 mi.) with the lowest APF level (0) for that sequence. Again, it can be seen that buildings 2-5 are consistently over-estimated, even on a relative scale. The distances to the two farthest buildings were under-estimated for the ∞ and 32,000 ft. conditions, relative to the farthest building under the 0 condition.

It should be remembered that the 0 condition represents a 0.5 visibility at 10,000 ft. slant range according to the formula presented above and in the Appendix.

An analysis of variance using the ratio scores yielded results similar to those presented in Tables 1 and 3 and is presented in Table 5. The means and standard deviations for the relative transformation are presented in Table 6.

Air Crew Member Subjects

The means of the estimated distances for the eight buildings at the four visibility levels are presented in Figures 7 and 8. The circled points in Figure 7 are the first five estimates. The means for the two sequences were not averaged for presentation due to the difference between the results of the two sequences. An analysis of variance performed on these data revealed a significant effect of APF in the first sequence ($p < 0.003$) but not the second ($p = 0.6$). There was not a significant difference between the sequences ($p > 0.5$). The source tables are presented in Table 7. The means and standard deviations for both sequences are presented in Table 8. A comparison of Figure 7 and Figure 8 suggests that the difference between the two sequences is due to the lower estimates for the first five stimulus presentations in the first sequence. Figures 7 and 8 reveal several interesting facts.

1. Air crew members (ACM), overall, are fairly accurate in their estimates of distances to the buildings.
2. There is little or no effect of APF on the distance estimates of the ACM, particularly in the second sequence.
3. ACM tend to give longer estimates in the second sequence over the first.
4. ACM over-estimate the distances to the middle buildings more than the others. Only two of the ACM were able to judge these distances accurately. On a relative scale, the second building was the most over-estimated (see Figure 9). ACM showed a fairly consistent 2 mile over-estimation of the distance to buildings 2-7.
5. ACM tend to under-estimate the distance to the first five buildings in the first sequence relative to their estimates of the same distances presented later in the first sequence and in the second.

TABLE 1

SOURCE TABLE FOR ANALYSIS OF VARIANCE OF
ESTIMATED DISTANCES BY STUDENT OBSERVERS

SOURCE	SS	DF	MS	F	P
Distance	164051.9375	7.	23435.9	12.8453	0.0000
Error	485312.7500	266.	1824.5		
Visibility	4654.1133	3.	1551.4	11.6826	0.0000
Error	15138.4492	114.	132.8		
Runs	3167.6038	1.	3167.6	0.1286	0.7223
Error	936251.7500	38.	24638.2		
Distance X Vis.	10912.0742	21.	519.6	6.4030	0.0000
Error	64759.8750	798.	81.2		
Distance X Runs	1516.8743	7.	216.7	0.1188	0.9960
Error	485312.7500	266.	1824.5		
Vis. X Runs	382.9441	3.	127.6	0.9613	0.5847
Error	15183.4492	114.	132.8		
Distance X Vis. X Runs	2658.2080	21.	126.6	1.5598	0.0520
Error	64759.8750	798.	81.2		

TABLE 2

MEANS AND DEVIATIONS OF ESTIMATED DISTANCES FOR STUDENT OBSERVERS

		Buildings (mi.)								
		.56	.94	1.6	2.2	3.2	4.3	5.6	7.1	ROW MEAN
1st Sequence	0	1.44	7.35	10.77	14.67	18.42	29.58	33.91	42.73	19.87
		1.33	10.81	12.26	17.23	33.39	43.12	60.97	68.20	
	8000	2.42	6.07	8.44	19.39	19.05	30.58	33.16	40.45	19.94
		2.85	5.76	8.82	28.50	25.46	46.98	56.01	58.49	
	32000	1.18	5.86	10.36	8.83	15.14	29.63	30.07	21.93	15.37
		0.60	5.73	11.76	9.86	32.59	47.27	55.32	43.71	
	∞	2.16	5.25	6.88	17.09	21.38	16.69	24.77	29.94	15.52
		2.35	5.15	8.56	23.66	34.06	32.67	33.67	47.08	
2nd Sequence	0	3.13	6.79	12.51	19.73	22.19	26.07	39.13	50.07	22.45
		3.43	7.59	16.63	28.89	28.95	32.29	61.65	73.39	
	8000	3.22	7.83	14.13	18.98	22.57	30.15	38.23	42.62	22.21
		3.58	8.58	18.20	28.36	28.74	45.61	62.27	58.47	
	32000	3.38	8.27	13.62	21.72	20.68	24.66	34.94	35.91	20.40
		4.03	8.68	21.92	33.69	24.20	43.49	57.04	56.24	
	∞	3.69	8.73	13.70	19.08	22.25	20.70	26.63	30.35	18.14
		4.17	9.30	17.64	28.62	34.37	24.80	44.89	46.42	

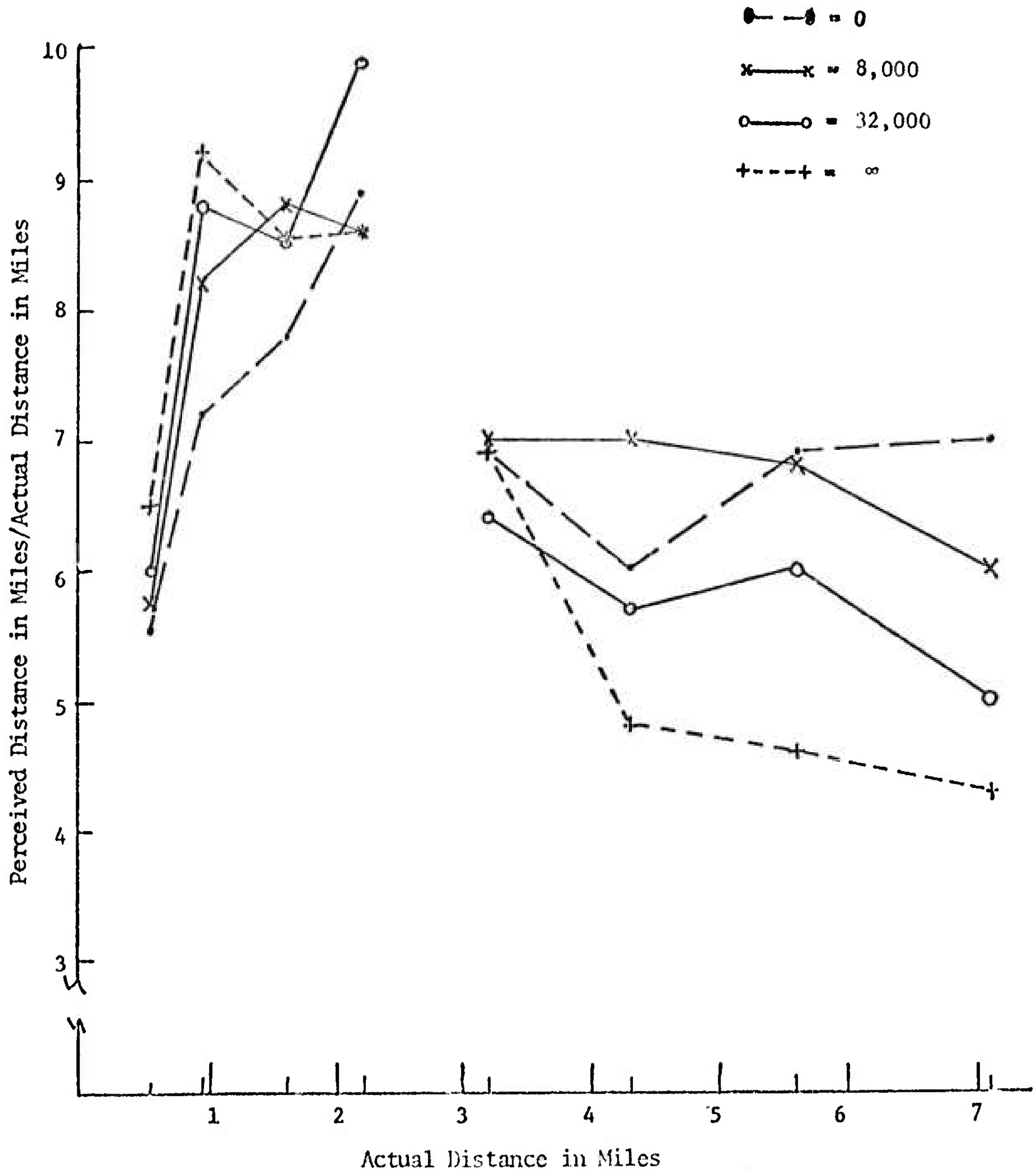

Figure 4. Relative over-estimation of distances in the second sequence. Student observers.

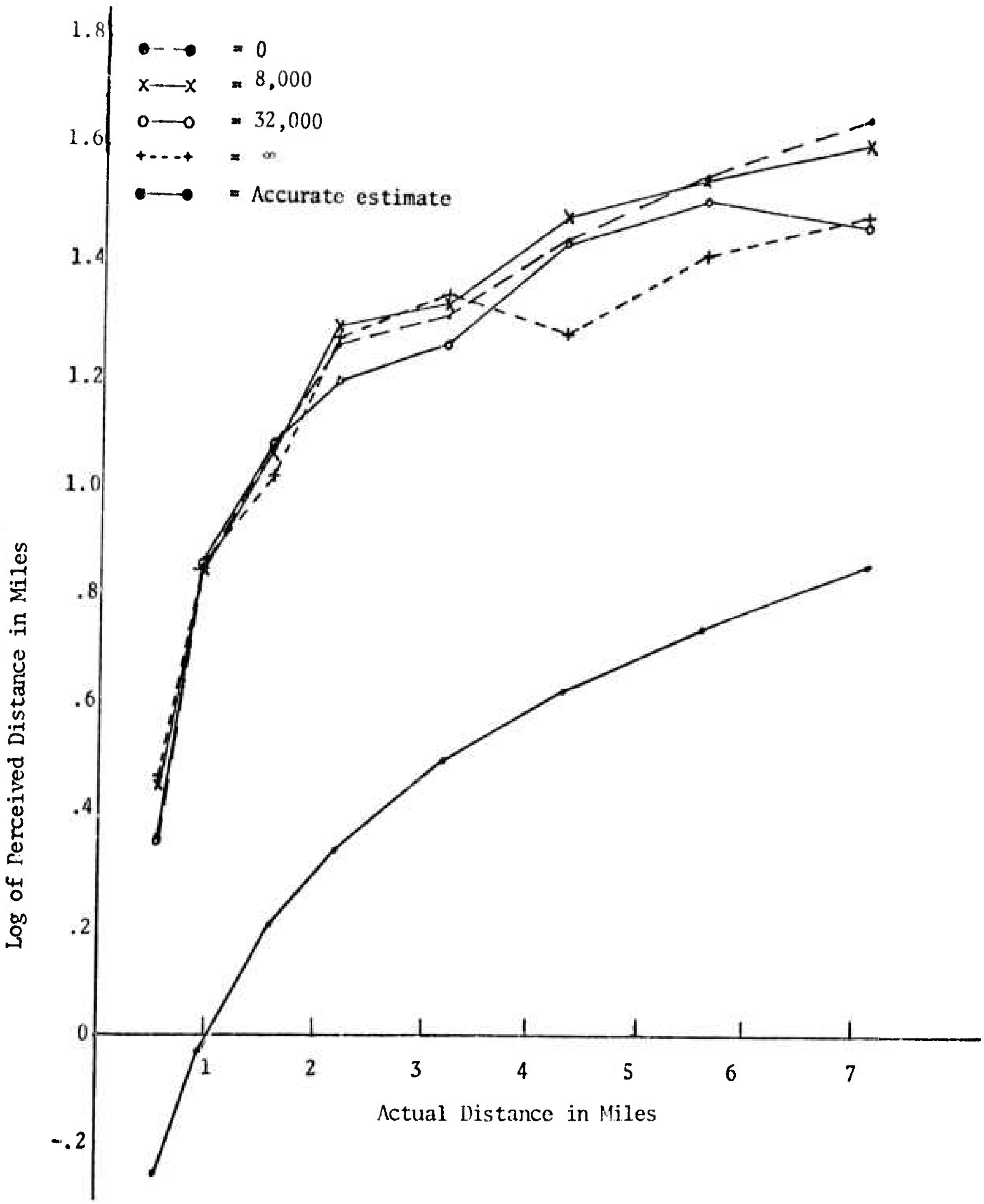

Figure 5. Log of perceived distance for runs 1 and 2. Student observers.

TABLE 3

SOURCE TABLE FOR ANALYSIS OF VARIANCE OF LOGARITHMIC TRANSFORMATION OF ESTIMATED DISTANCES FOR STUDENT OBSERVERS

SOURCE	SS	DF	MS	F	P
Distance	72.6212	7.	10.37	101.6612	< .001
Error	27.1451	266.	0.10		
Visibility	0.6689	3.	0.22	17.4156	< .001
Error	1.4595	114.	0.01		
Runs	3.1710	1.	3.17	0.5042	0.511
Error	238.9688	38.	6.29		
Distance X Vis.	1.4078	21.	0.07	6.8576	< .001
Error	7.8013	798.	0.01		
Distance X Runs	0.2796	7.	0.04	0.3914	0.907
Error	27.1451	266.	0.10		
Visibility X Runs	0.2014	3.	0.07	5.2441	0.002
Error	1.4595	114.	0.01		
Distance X Vis. X Runs	1.1363	21.	0.05	5.5351	< .001
Error	7.8013	798.	0.01		

TABLE 4

LOGARITHM OF MEAN AND STANDARD DEVIATION OF ESTIMATED DISTANCES BY STUDENT OBSERVERS

		Buildings (mi.)								
		.56	.94	1.6	2.2	3.2	4.3	5.6	7.1	ROW MEAN
1st Sequence	0	.159	.086	1.032	1.147	1.265	1.265	1.471	1.630	1.296
		.124	1.034	1.089	1.236	1.524	1.634	1.785	1.834	
	8000	.383	.783	.926	1.290	1.279	1.485	1.520	1.606	1.299
		1456	.761	.946	1.454	1.406	1.672	1.748	1.767	
	32000	.072	.768	1.015	.945	1.180	1.471	1.478	1.321	1.191
		.220	.758	1.070	.994	1.513	1.674	1.743	1.640	
	∞	.335	.720	.084	1.232	1.330	1.222	1.393	1.476	1.351
		.372	.712	.932	1.374	1.532	1.514	1.527	1.673	
2nd Sequence	0	.496	.832	1.098	1.295	1.346	1.416	1.592	1.699	1.351
		.536	.880	1.221	1.460	1.462	1.594	1.789	1.866	
	8000	.508	.894	1.150	1.278	1.353	1.479	1.582	1.629	1.347
		.554	.933	1.260	1.453	1.458	1.679	1.794	1.767	
	32000	.529	.918	1.134	3.336	1.315	1.381	1.543	1.555	1.309
		.605	.938	1.341	1.528	1.384	1.638	1.756	1.750	
	∞	.567	.941	1.137	1.280	1.347	1.316	1.425	1.482	1.259
		.620	.968	1.246	1.456	1.536	1.394	1.652	1.667	

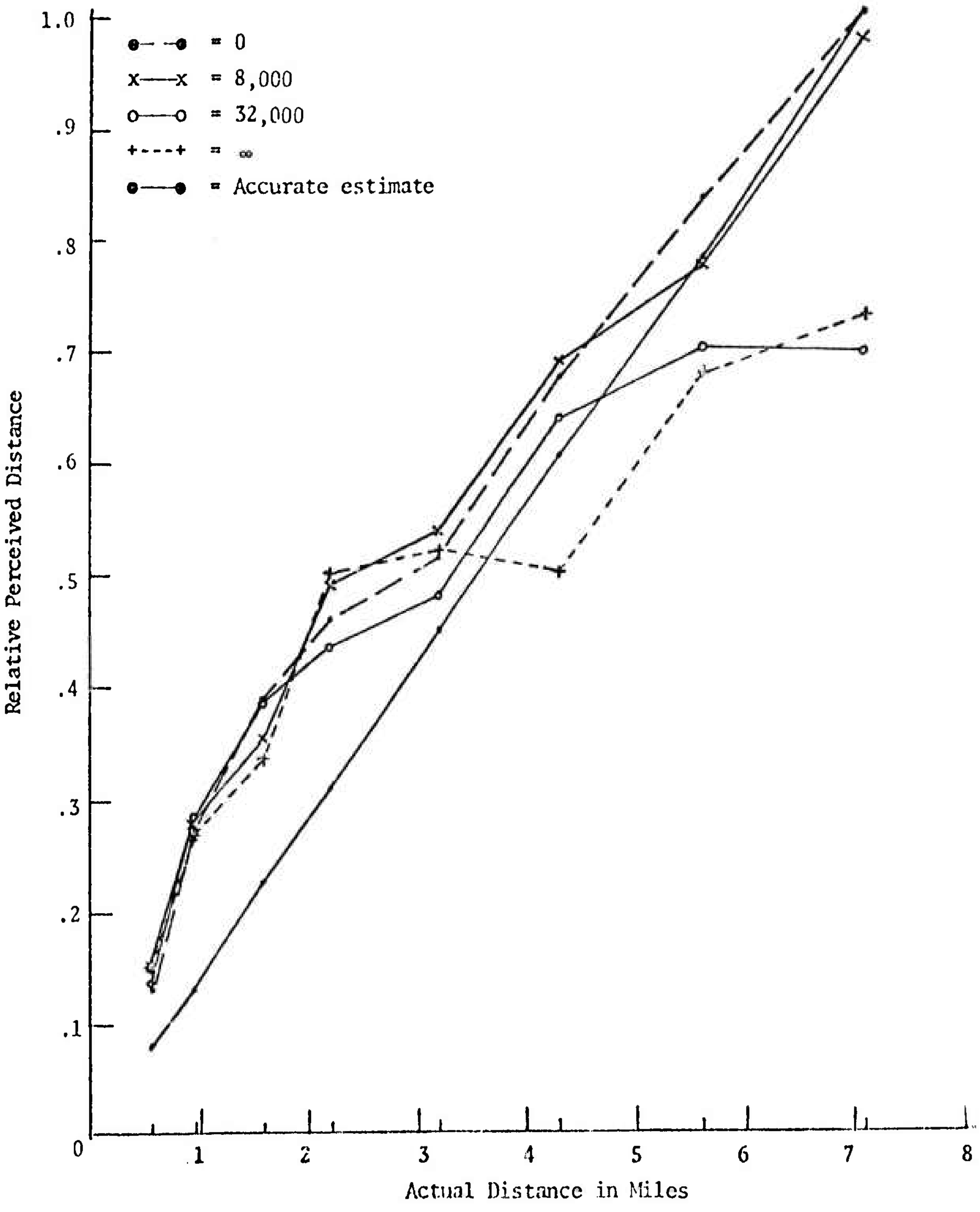

Figure 6. Relative perceived distance (relative to farthest building at 0 visibility) for runs 1 and 2. Students observers.

TABLE 5

SOURCE TABLE FOR ANALYSIS OF VARIANCE OF RELATIVE TRANSFORMATION OF DISTANCE ESTIMATES BY STUDENTS

SOURCE	SS	DF	MS	F	P
Distance	63.544[illegible]	7.	9.07	366.0112	< .001
Error	6.5973	266.	2.2		
Visibility	1.4674	3.	0.49	32.6726	< .001
Error	1.7067	114.	0.015		
Runs	0.0260	1.	0.03	1.0	.823
Error	21.0058	38.	0.553		
Distance X Vis.	3.3420	21.	0.16	12.5732	< .001
Error	10.1005	798.	0.013		
Distance X Runs	0.3474	7.	0.05	2.0013	> .05
Error	6.5973	266.	0.02		
Vis. X Runs	0.1855	3.	0.06	4.1306	.008
Error	1.7067	114.	0.01		
Distance X Vis. X Runs	1.5909	21.	0.08	5.9854	< .001
Error	10.1005	798.	0.01		

TABLE 6

MEAN AND STANDARD DEVIATION OF RELATIVE TRANSFORMATION OF ESTIMATED DISTANCES BY STUDENT OBSERVERS

		Buildings (mi.)								
		.56	.94	1.6	2.2	3.2	4.3	5.6	7.1	ROW MEAN
1st Sequence	0	0.11	0.29	0.39	0.43	0.47	0.74	0.81	1.00	0.53
		0.10	0.17	0.17	0.18	0.18	0.23	0.18	0.00	
	8000	0.15	0.29	0.31	0.51	0.52	0.71	0.78	1.01	0.54
		0.12	0.17	0.16	0.22	0.16	0.16	0.12	0.28	
	32000	0.12	0.28	0.39	0.38	0.40	0.71	0.69	0.57	0.44
		0.11	0.17	0.18	0.19	0.17	0.22	0.15	0.24	
	∞	0.14	0.24	0.29	0.48	0.54	0.44	0.74	0.76	0.45
		0.11	0.13	0.15	0.16	0.16	0.17	0.23	0.21	
2nd Sequence	0	0.15	0.24	0.38	0.47	0.55	0.60	0.85	1.00	0.53
		0.13	0.15	0.17	0.18	0.16	0.18	0.20	0.00	
	8000	0.14	0.26	0.38	0.46	0.54	0.65	0.76	0.93	0.52
		0.12	0.15	0.17	0.17	0.16	0.24	0.13	0.18	
	32000	0.15	0.28	0.37	0.49	0.55	0.56	0.71	0.81	0.49
		0.12	0.16	0.17	0.16	0.20	0.17	0.12	0.17	
	∞	0.16	0.29	0.37	0.51	0.49	0.55	0.61	0.69	0.46
		0.12	0.15	0.16	0.43	0.15	0.20	0.21	0.17	

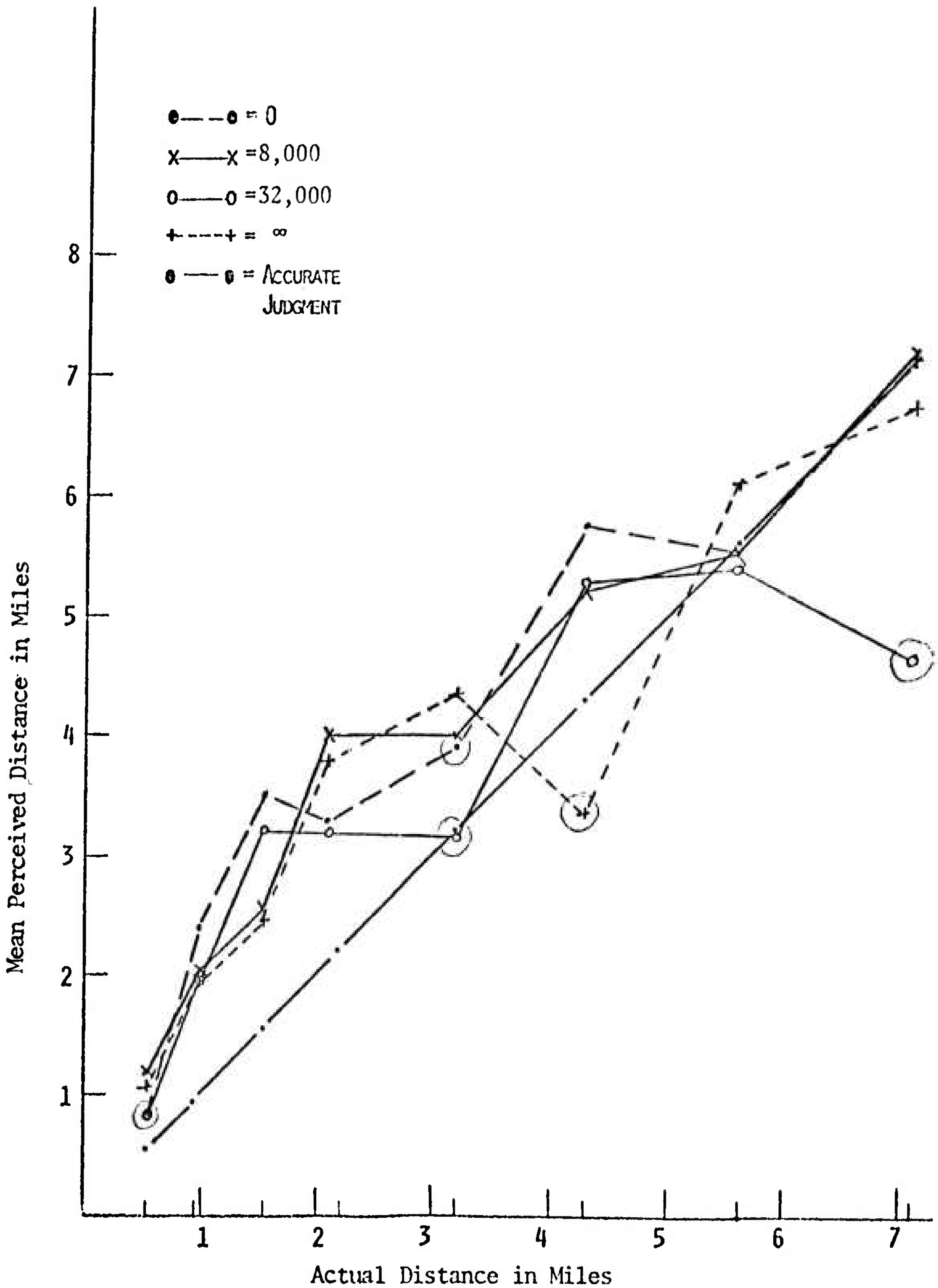

Fig. 7. Raw score data for ACM observers. First run. Circled points are first five observations.

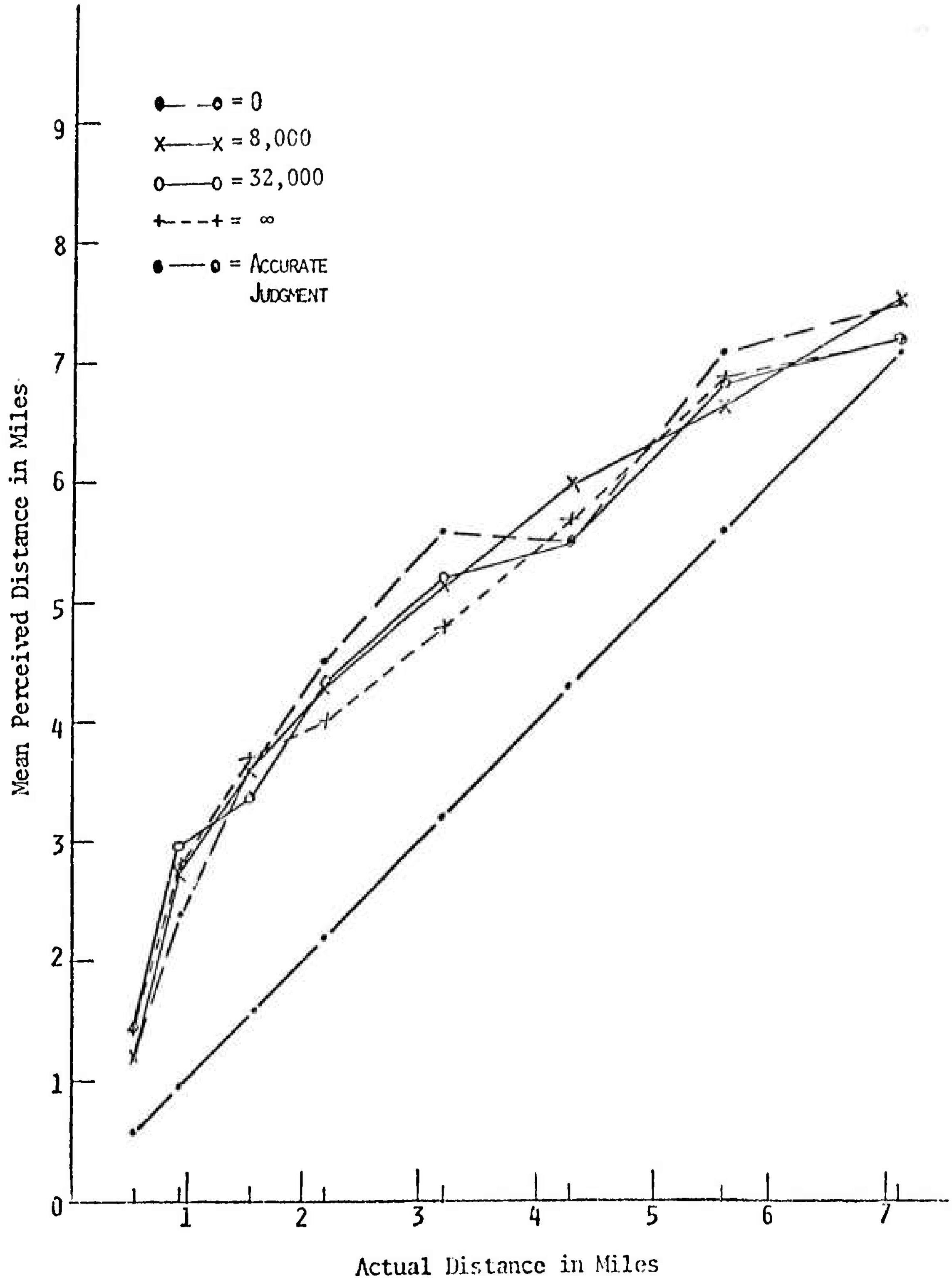

Fig. 8. Raw score data for ACM observers. Second run.

TABLE 7

SOURCE TABLE FOR ANALYSIS OF VARIANCE
OF ESTIMATED DISTANCE BY AIR CREW MEMBER OBSERVERS

Sequence 1

SOURCE	SS	DF	MS	F	P
Distances	933.3413	7.	133.3	28.4611	<.001
Error	295.1426	63.	4.7		
Visibility	17.0095	3.	5.67	5.9370	0.003
Error	25.7849	27.	0.95		
Distances X Vis.	84.7588	21.	4.04	4.855	<.001

Sequence 2

SOURCE	SS	DF	MS	F	P
Distances	1194.2283	7.	170.6	21.9899	<.001
Error	488.7725	63.	7.76		
Visibility	0.5165	3.	0.17	0.5709	0.642
Error	8.1420	27.	0.30		
Distances X Vis.	10.5615	21.	0.50	1.4429	0.10
Error	65.8778	189.	0.35		

TABLE 8

MEAN AND STANDARD DEVIATION OF ESTIMATED DISTANCES BY AIR CREW MEMBERS

		Buildings (mi.)								
		.56	.94	1.6	2.2	3.2	4.3	5.6	7.1	ROW MEAN
1st Sequence	0	0.85 0.33	2.41 1.46	3.52 1.89	3.38 1.55	3.86 1.38	5.73 3.26	5.56 2.42	7.16 3.60	4.06
	8000	1.15 0.64	1.98 1.10	2.53 1.19	3.97 1.79	4.02 1.96	5.21 2.76	5.55 2.63	7.18 4.52	3.95
	32000	0.83 0.28	1.95 1.01	3.20 1.63	3.22 1.52	3.13 0.98	5.29 2.97	5.41 2.26	4.65 1.70	3.46
	∞	1.04 0.53	1.95 1.10	2.45 0.90	3.78 1.85	4.33 2.11	3.33 0.95	6.08 3.43	6.72 3.87	3.71
2nd Sequence	0	1.17 0.74	2.38 1.50	3.62 2.24	4.51 2.66	5.59 3.68	5.53 2.95	7.18 4.25	7.50 4.51	4.68
	8000	1.19 0.70	2.77 1.61	3.60 2.16	4.27 2.65	5.14 2.90	6.00 3.90	6.65 3.73	7.52 4.56	4.64
	32000	1.44 0.91	2.96 1.86	3.36 2.14	4.35 2.53	5.21 3.13	5.52 2.82	6.84 3.90	7.20 4.27	4.61
	∞	1.42 0.91	2.82 1.88	3.69 2.16	4.08 2.28	4.80 2.78	5.72 3.71	6.88 4.63	7.21 4.41	4.57

Figures 10 and 11 present the logarithmic transformation of the mean estimated distances for the first and second sequence. Again, the errors are over-estimation, particularly for the middle buildings, and the second sequence. An analysis of variance using the transformed scores revealed no significant difference between APF levels in the second sequence. There was an effect in the first sequence. The source tables are presented in Table 9 and the means and standard deviations are presented in Table 10.

In Figures 12 and 13 are presented a relative transformation of the distance estimates. Each estimation is displayed as a ratio of each estimate to the estimate of the distance to the farthest building (7.1 mi.) at the lowest visibility (0). Again, these figures indicate that the distances to buildings 2-5 are consistently over-estimated, even on a relative scale. An analysis of variance using the transformed scores produced results similar to those presented in Tables 7 and 9, and is presented in Table 11. Means and standard deviations following the transformation are presented in Table 12.

Comparison of Student and Air Crew Member Observers

A comparison of Figures 1-6 (student data) with Figures 7-13 (ACM data) reveals several points:

1. Unlike naive student subjects, ACM tended to ignore the differences in the APF levels when making their distance estimates. Results of the second sequence for students revealed clear differences while the results for ACM revealed no differences in the second sequence, as a function of APF.
2. ACM, overall, are more accurate in their distance estimates than naive student observers.
3. ACM and students both tend to increase their distance estimates in the second sequence over the first. ACM are more accurate in the first sequence.
4. Students over-estimate the distance to the second, third and fourth buildings more than the others. This is especially clear in Figure 4.
5. On a relative scale ACM tend to over-estimate the distance to the second building more than the others (see Figure 9). On the actual scale, however, ACM over-estimate the second through seventh buildings by a fairly consistent 2.0 miles.
6. Both ACM and students gave lower estimates of the distance to the first five buildings in the first sequence relative to their estimates of the distances to the same buildings presented later in the first sequence and in the second sequence.
7. A closer examination of the data for both students and ACM revealed that stimulus sequence has some effect, particularly on the estimates of the distance to the middle buildings. When these middle buildings appear after a farther building, they are judged as being closer than when they appear following a closer building.

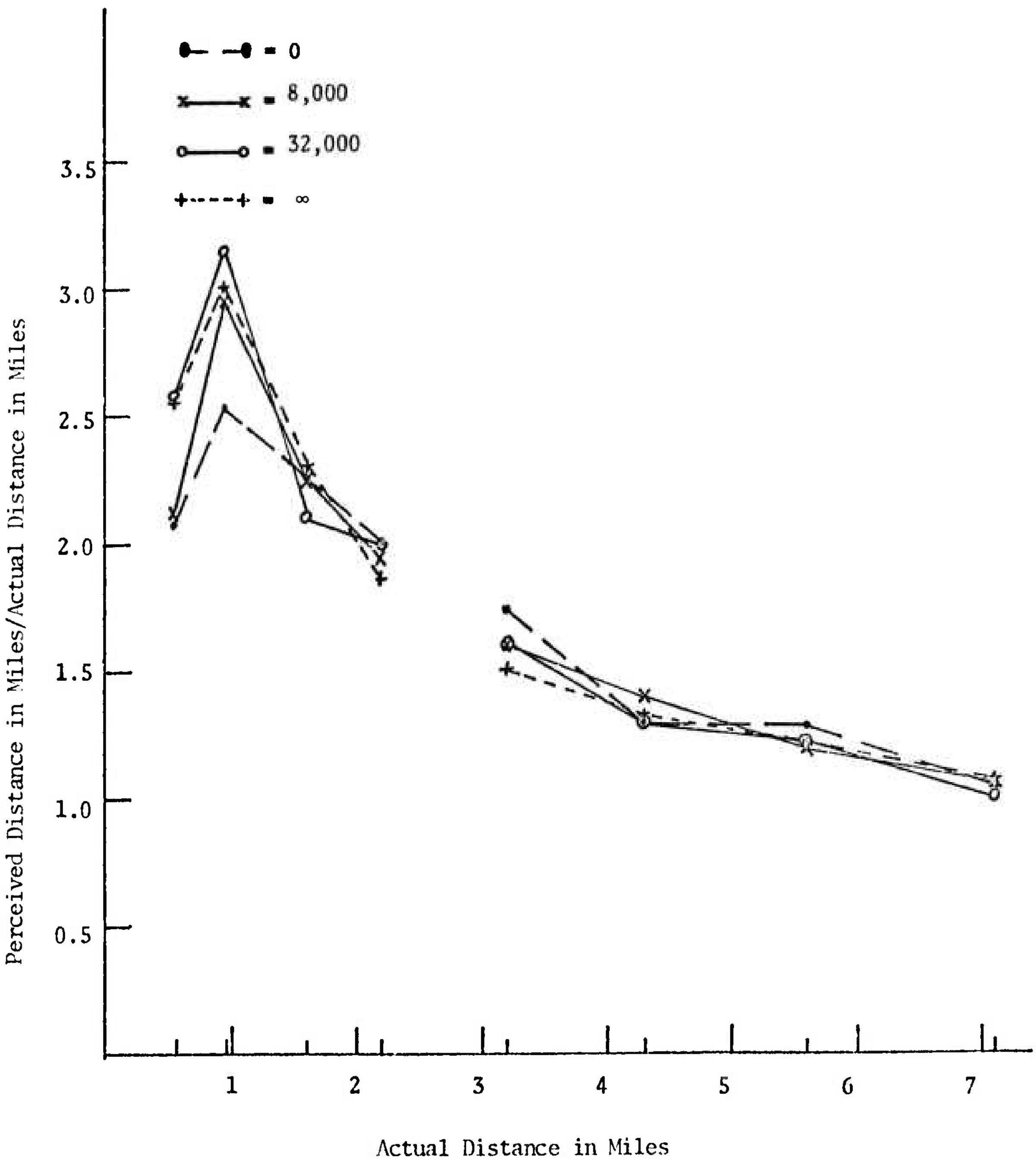

Figure 9. Relative over-estimation of distances in the second sequence. ACM observers.

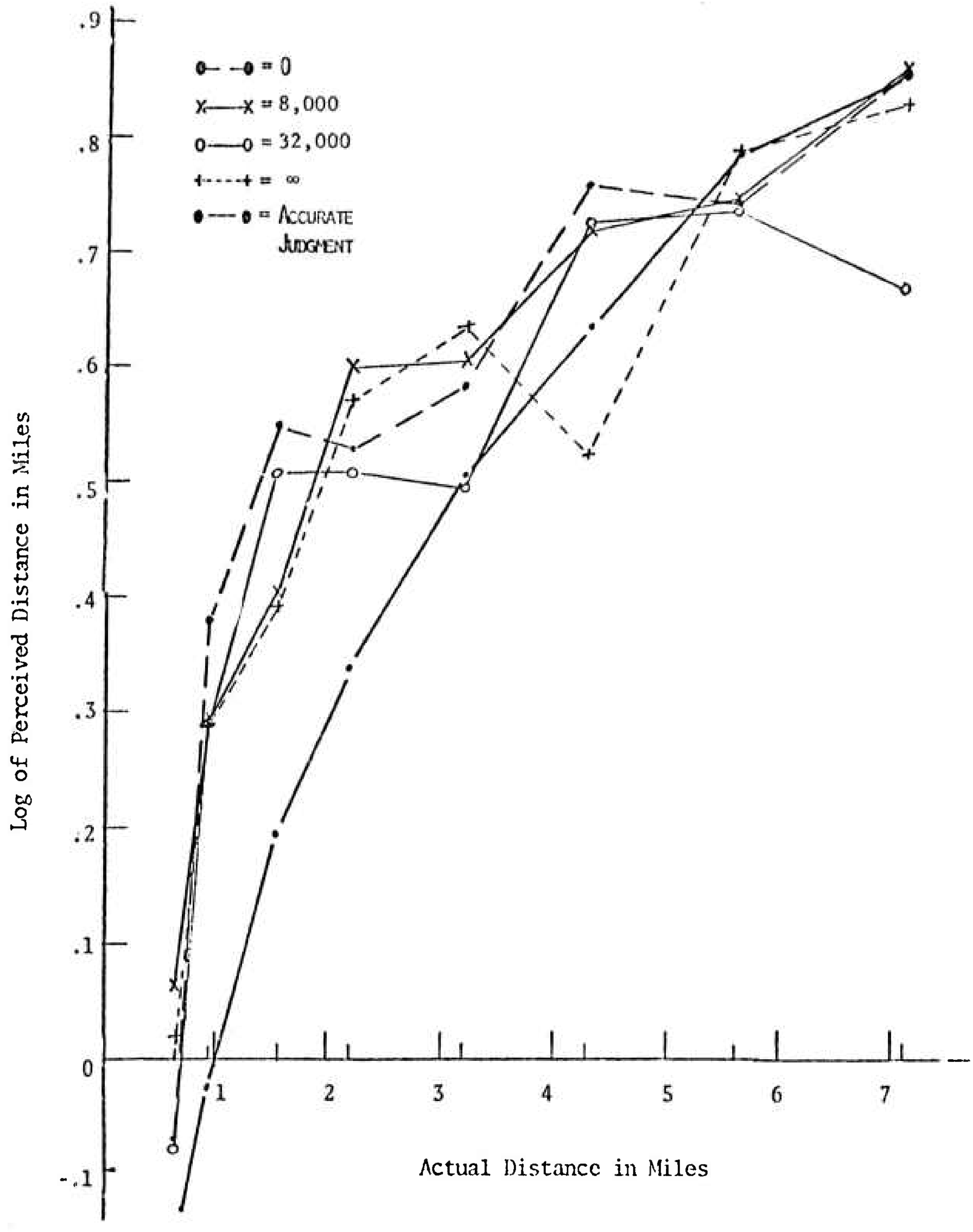

Fig. 10. Logarithmic transform of raw score estimates for ACM observers. First run.

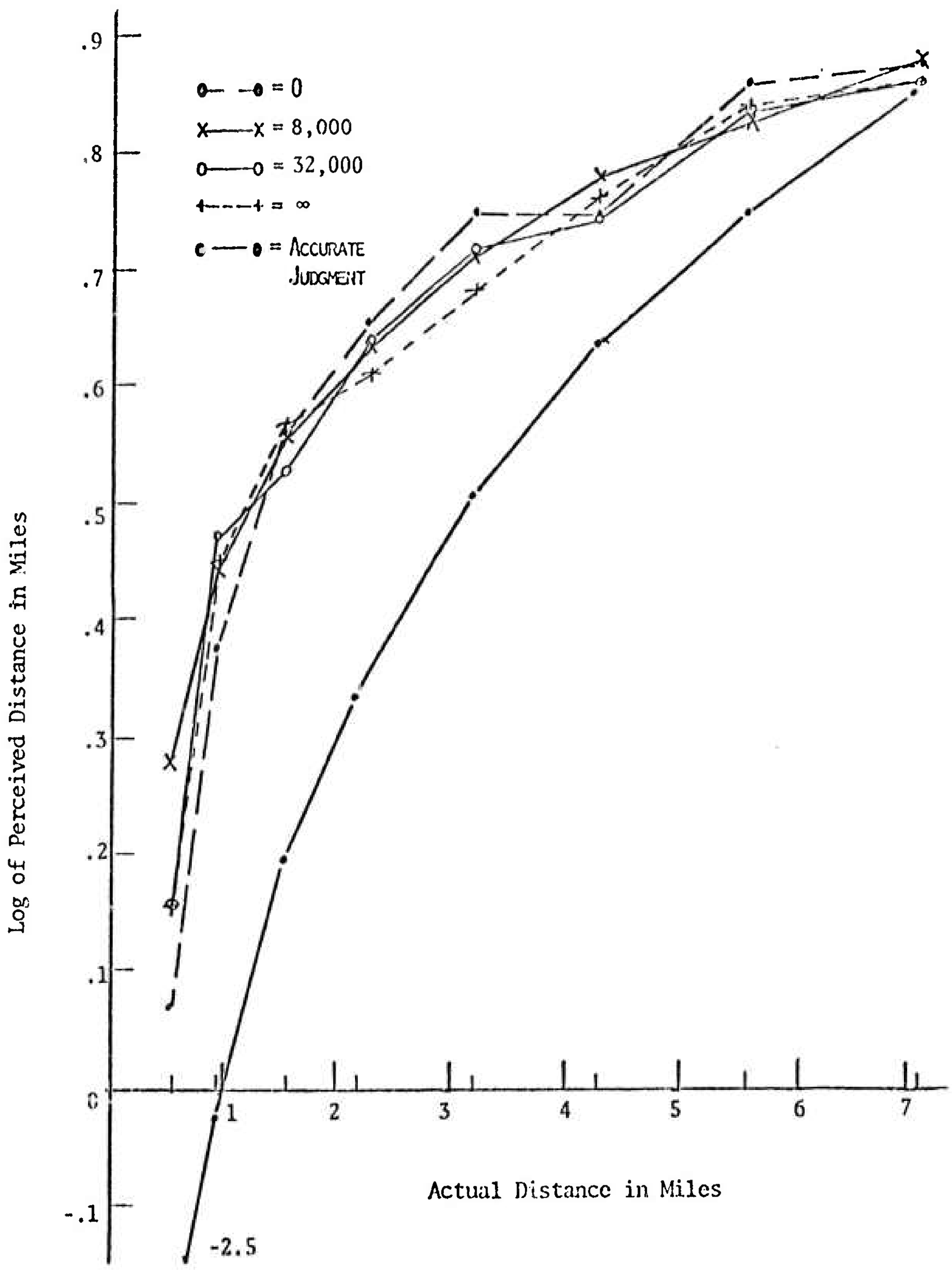

Fig. 11. Logarithmic transform of raw score data for ACM observers Second run.

TABLE 9

SOURCE TABLE FOR ANALYSIS OF VARIANCE OF LOGARITHMIC TRANSFORMATION OF ESTIMATED DISTANCES FOR AIR CREW MEMBER OBSERVERS

Sequence 1

SOURCE	SS	DF	MS	F	P
Distances	9.1945	7.	1.31	87.5656	<.001
Error	0.9450	63.	0.015		
Visibility	0.0813	3.	0.03	5.6665	0.004
Error	0.1291	27.	0.005		
Distances X Vis.	0.3758	21.	0.018	4.9503	<.001
Error	0.6832	189.	0.004		

Sequence 2

SOURCE	SS	DF	MS	F	P
Distances	8.8639	7.	1.27	85.6129	<.001
Error	0.9318	63.	0.015		
Visibility	0.0010	3.	0.0003	0.2377	0.869
Error	0.0396	27.	0.0015		
Distances X Vis.	0.0678	21.	0.003	1.7016	0.033
Error	0.3588	189.	0.0019		

TABLE 10

LOGARITHM OF MEAN AND STANDARD DEVIATION OF ESTIMATED DISTANCES BY AIR CREW MEMBERS

		Buildings (mi.)								
		.56	.94	1.6	2.2	3.2	4.3	5.6	7.1	ROW MEAN
1st Sequence	0	-.0706 -.471	.3829 .166	.5465 .277	.5295 .192	.5866 .141	.7581 .513	.7450 .385	.8549 .557	.608
	8000	.0626 -.191	.2967 .044	.4040 .075	.5988 .253	.6042 .292	.7173 .442	.7443 .421	.8564 .656	.597
	32000	-.0809 -.544	.2900 .008	.5058 .214	.5078 .182	.4962 -.007	.7234 .473	.7332 .256	.6674 .230	.539
	∞	.0170 -.273	.2911 .041	.3900 -.046	.5781 .269	.6364 .326	.5231 -.019	.7843 .535	.8276 .588	.570
2nd Sequence	0	.068 -.126	.3774 .176	.5587 .350	.6546 .425	.7474 .566	.7431 .471	.8564 .629	.8753 .654	.671
	8000	.2787 -.152	.4424 .207	.5563 .336	.6304 .424	.7113 .462	.7781 .592	.8231 .572	.8762 .659	.667
	32000	.1598 -.039	.4713 .271	.5269 .331	.6389 .403	.7169 .497	.7419 .451	.8351 .591	.8573 .631	.664
	∞	.1538 -.039	.4510 .275	.5670 .336	.6112 .359	.6812 .444	.7574 .570	.8376 .666	.8579 .645	.661

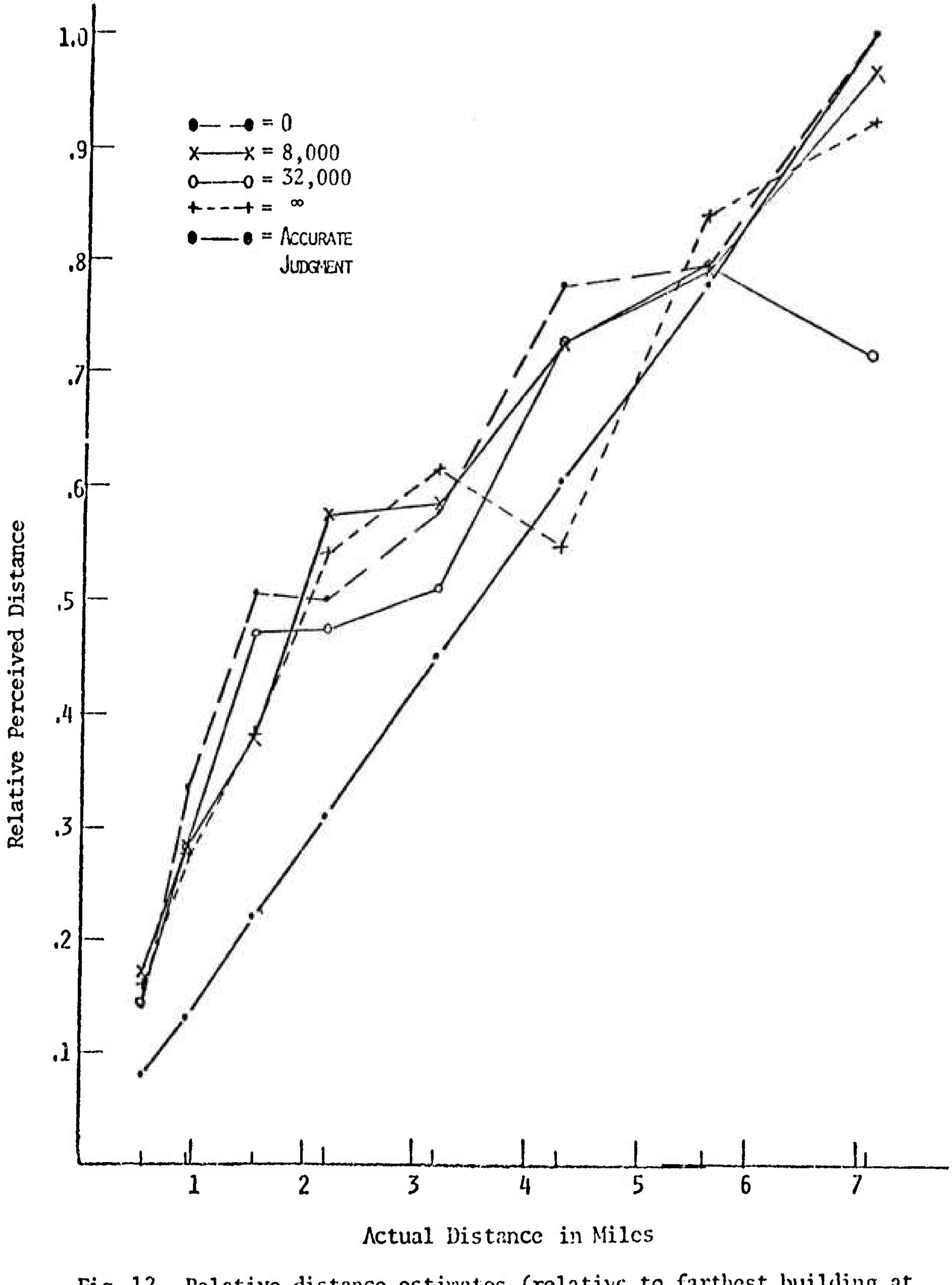

Fig. 12. Relative distance estimates (relative to farthest building at lowest visibility) for ACM observers. First run.

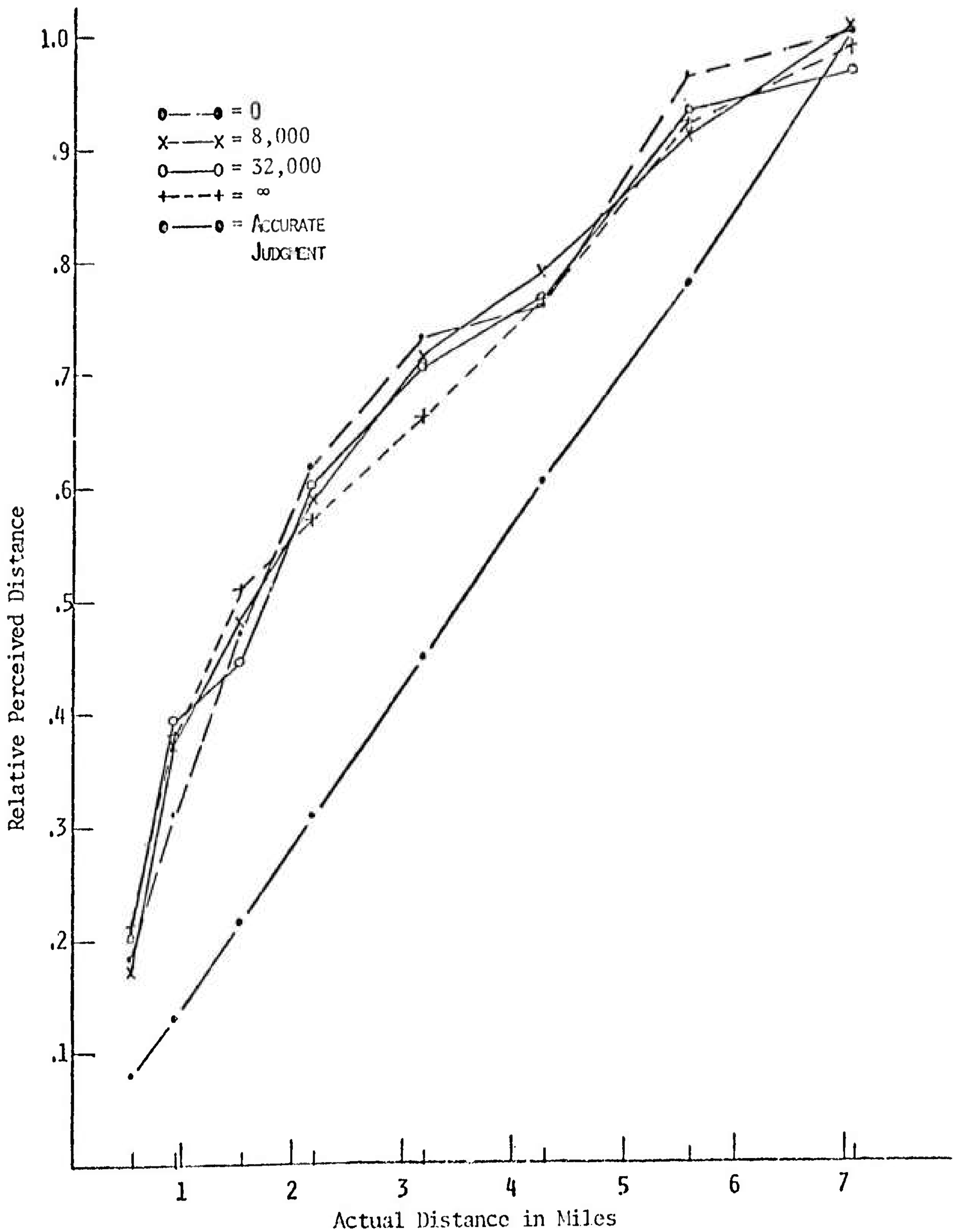

Fig. 13. Relative distance estimates (relative to farthest building at lowest visibility) for ACM observers. Second run.

TABLE 11

SOURCE TABLE FOR RELATIVE TRANSFORMATION OF ESTIMATED DISTANCES FOR AIR CREW MEMBERS

SOURCE	SS	DF	MS	F	P
Distance	39.1437	7.	5.59	266.7805	< .001
Error	2.6411	126.	.02		
Visibility	0.1128	3.	.04	4.5318	.006
Error	0.4482	54.	.004		
Runs	1.0649	1.	1.06	6.3455	.020
Error	3.0208	18.	.009		
Distance x Vis.	0.5084	21.	.024	3,7881	< .001
Error	2.4158	378.	.006		
Distance x Runs	0.1638	7.	.02	1.1167	> .05
Error	2.6411	126.	.02		
Vis. x Runs	0.0795	3.	.03	3.1920	.030
Error	0.4482	54.	.008		
Distance x Vis. x Runs	0.5451	21.	.003	4.0614	< .001
Error	2.4158	378.	.006		

TABLE 12

MEAN AND STANDARD DEVIATION OF RELATIVE TRANSFORMATION OF ESTIMATED DISTANCES FOR AIR CREW MEMBERS

		Buildings (mi.)								
		.56	.94	1.6	2.2	3.2	4.3	5.6	7.1	ROW MEAN
1st Sequence	0	0.13 0.07	0.33 0.12	0.50 0.14	0.50 0.14	0.57 0.12	0.77 0.12	0.79 0.07	1.00 0.00	0.57
	8000	0.17 0.08	0.27 0.13	0.37 0.11	0.57 0.13	0.58 0.14	0.72 0.13	0.78 0.09	0.96 0.11	0.55
	32000	0.14 0.08	0.28 0.11	0.46 0.14	0.47 0.13	0.51 0.21	0.72 0.09	0.79 0.11	0.71 0.21	0.51
	∞	0.15 0.07	0.27 0.11	0.38 0.13	0.54 0.13	0.61 0.12	0.54 0.19	0.83 0.09	0.92 0.09	0.53
2nd Sequence	0	0.18 0.09	0.31 0.09	0.47 0.11	0.61 0.13	0.73 0.12	0.75 0.07	0.96 0.07	1.00 0.00	0.62
	8000	0.17 0.07	0.37 0.12	0.48 0.10	0.58 0.17	0.71 0.13	0.78 0.08	0.90 0.08	1.02 0.15	0.63
	32000	0.20 0.08	0.39 0.13	0.44 0.11	0.60 0.13	0.70 0.10	0.76 0.07	0.93 0.06	0.96 0.05	0.62
	∞	0.21 0.12	0.37 0.12	0.51 0.14	0.57 0.14	0.66 0.12	0.75 0.09	0.92 0.14	0.98 0.19	0.62

EXPERIMENT II

Texture

Subjects

The subjects were 20 additional students from the Introductory Psychology class at Wright State University. They were between the ages of 18 and 25 and had no previous piloting or sky jumping experience. Most had had some experience flying. All subjects had 20-20 vision (2 wore corrective lenses) and normal color vision.

In addition, 10 air crew members (9 pilots, 1 navigator) from Wright Patterson AFB personnel, the Ohio Air National Guard and Montgomery County Airport personnel volunteered to participate for purposes of comparison with the students. The number of flying hours varied widely among the pilots (150-1600 hours).

None of the students or air crew members were informed of the purpose of the experiment until the conclusion of the session, when all subjects were thoroughly debriefed. Participation by both groups was voluntary.

Stimulus Display

Apparatus. The Advent Projection System and Sony Videocassette Recorder were used. The same precautions for focus and convergence of the beams were taken as in Experiment I.

Stimuli. The size, distance, and number of buildings were the same as in Experiment I. The buildings were presented on four different backgrounds. One consisted of a plain green field as was used in the first experiment. The other three backgrounds consisted of a texture pattern which was produced by overlaying stripes of two different shades of green at right angles to each other. The widths of the stripes were 1000 ft., 2000 ft. and 4000 ft., thereby producing three different patterns of "blocks." The patterns were not regular checkerboards, however, due to the random selection of stripes to be displayed at any given point of intersection of the stripes. While there were occasionally large areas of the same color, the size of these areas was determined by the width of the stripes. Thus, the 1000 ft. condition produced the most dense pattern and the 4000 ft. condition the least dense. An aerial perspective factor of 32,000 ft. + 10 (1000 ft. altitude) was used for all stimulus conditions. This APF level was chosen as a result of Experiment I which indicated that this level produced more accurate distance estimates than the 0 or 8000 APF level conditions.

Each stimulus pair was presented on each of the four backgrounds for a total of 32 stimulus conditions. Stimuli were presented in blocks of eight buildings, randomly ordered, with each texture condition represented twice in two randomized orders. The sequence of each block was reversed for a second run. Stimuli were presented for 20 seconds each with 10 seconds of blue "sky" between stimulus frames. Subjects were also shown the same warm-up video-tape as used in Experiment 1.

Procedure

The procedure was the same as in the first experiment with the exception of the stimulus order. Each block of eight distances was reversed in the second sequence instead of the entire sequence as in the first experiment.

Results

The results of this experiment indicate that a texture gradient is used as a cue to distance by naive student observers and ACM observers. The size of the texture pattern is a significant variable in determining the responses of both groups.

Student Observers. The mean distance estimates for the eight buildings for all four texture conditions are presented in Figures 14-16. Figure 14 presents the results for the first sequence; Figure 15, the second sequence; and Figure 16, the mean of the two sequences. The circled points in Figure 14 indicate the first 8 stimulus conditions. The results can be summarized as follows:

1. Naive observers over-estimate the distances to all the buildings. However, comparison of Figures 14-16 with Figures 1-3 of Experiment 1 indicates that texture significantly reduced the over-estimation.
2. Texture size has little effect upon the estimation of distance to the first five buildings, and a significant effect upon that of the last three buildings. The 2000 ft. condition produced the most accurate estimates, while the 0 and 1000 ft. conditions produced the greatest over-estimates (see Figure 16). An analysis of variance revealed a significant difference among the texture conditions ($F = 4.99$; $p = .003$) (see Table 13). The mean and standard deviations for both sequences are presented in Table 14.
3. Comparison of Figures 14 and 15 indicates that there are some order effects within the first sequence, despite the careful randomization procedure. Estimates tended to increase in the second sequence over the first. [However, an analysis of variance indicated no significant difference between the sequences ($F < 1$, see Table 13)].
4. Figure 17 presents the relative over-estimation of distances to the eight buildings for each texture condition. The squares indicate the results that would have been obtained if the subjects had assumed (or perceived) the buildings to be equally spaced at distances of 1, 2, 3, 4, 5, 6, 7, and 8 miles. The

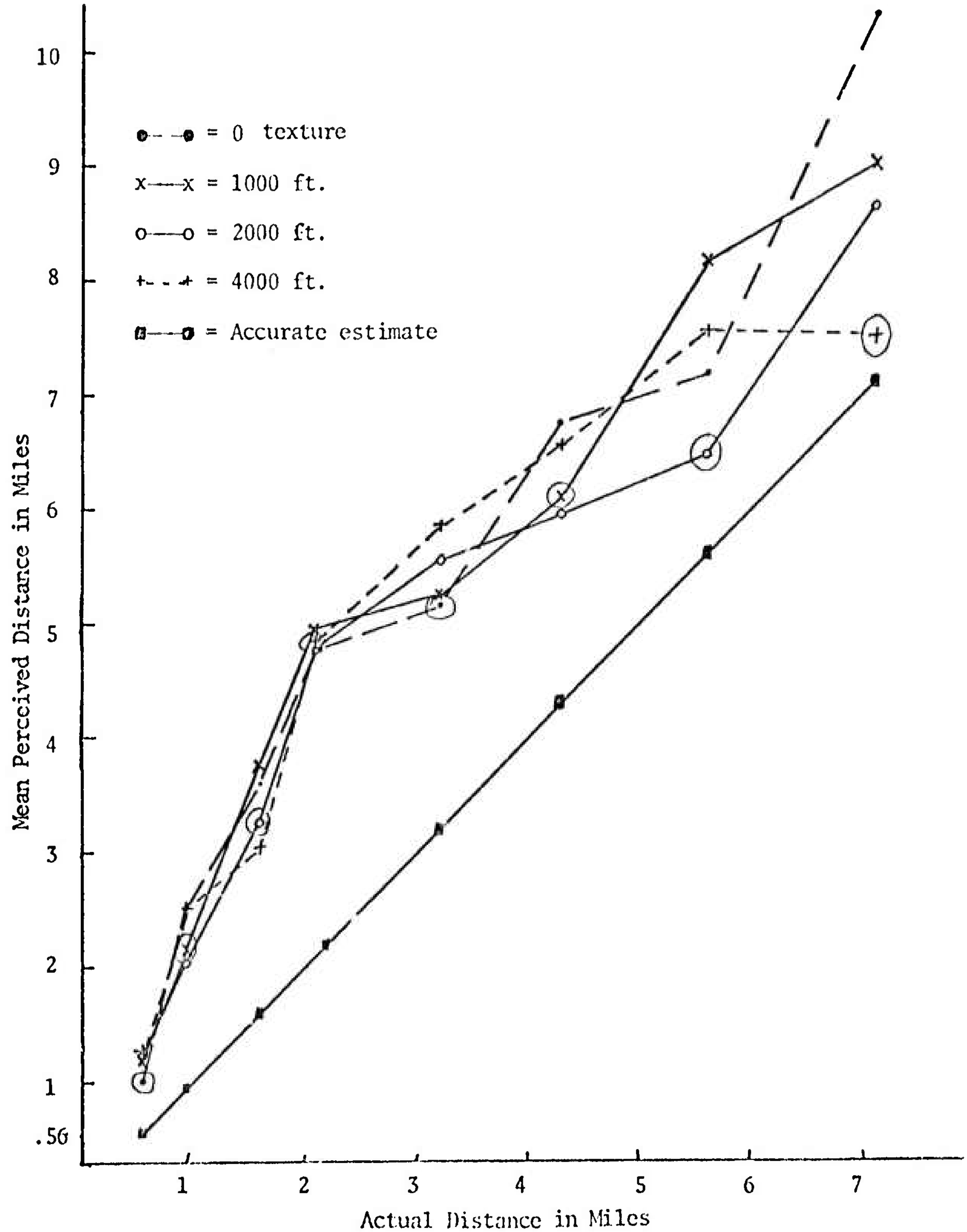

Figure 14. Mean raw score distance estimates for the first sequence. Student observers. Circled points indicate first responses for each of the eight buildings.

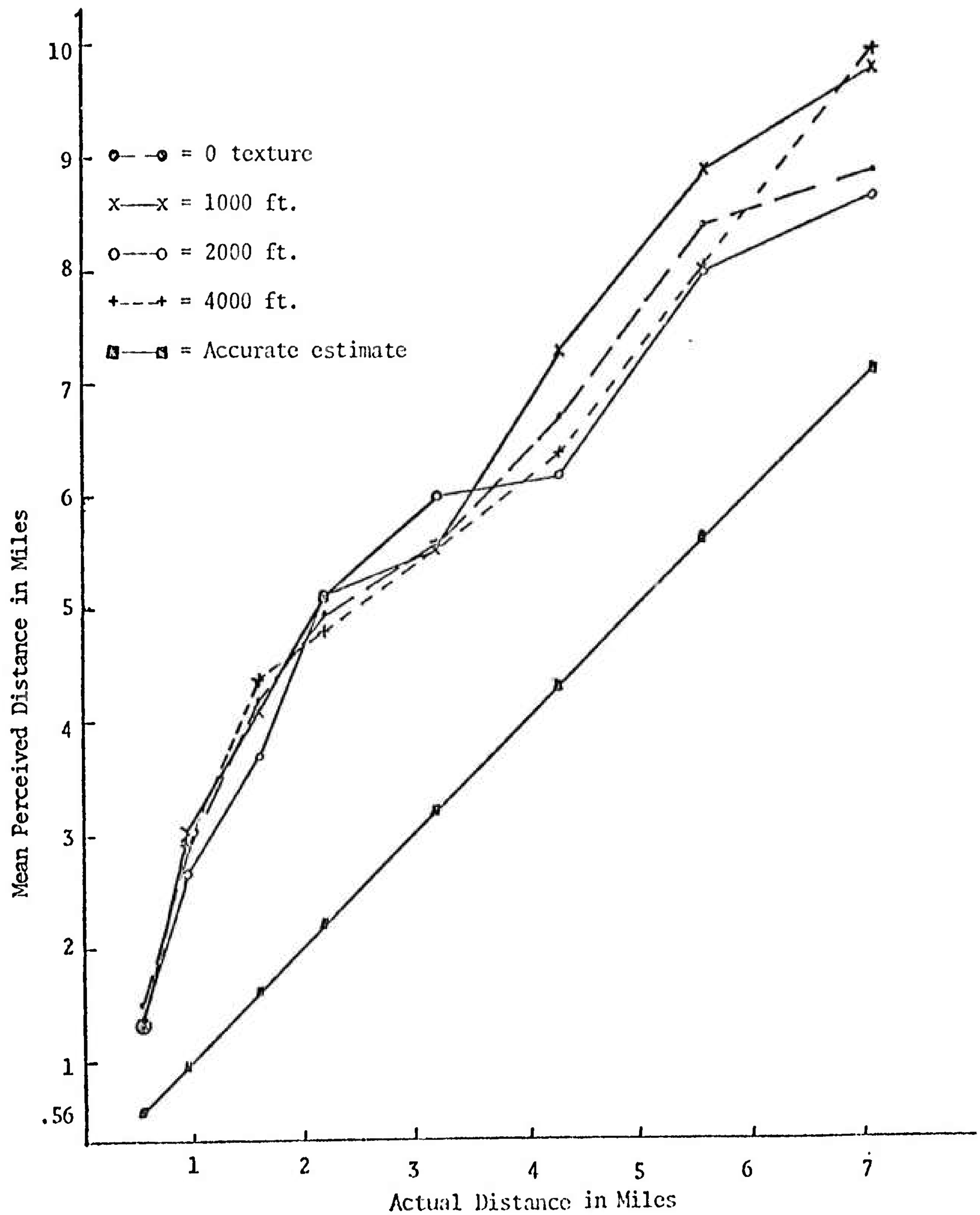

Figure 15. Mean raw score distance estimates for the second sequence. Student observers.

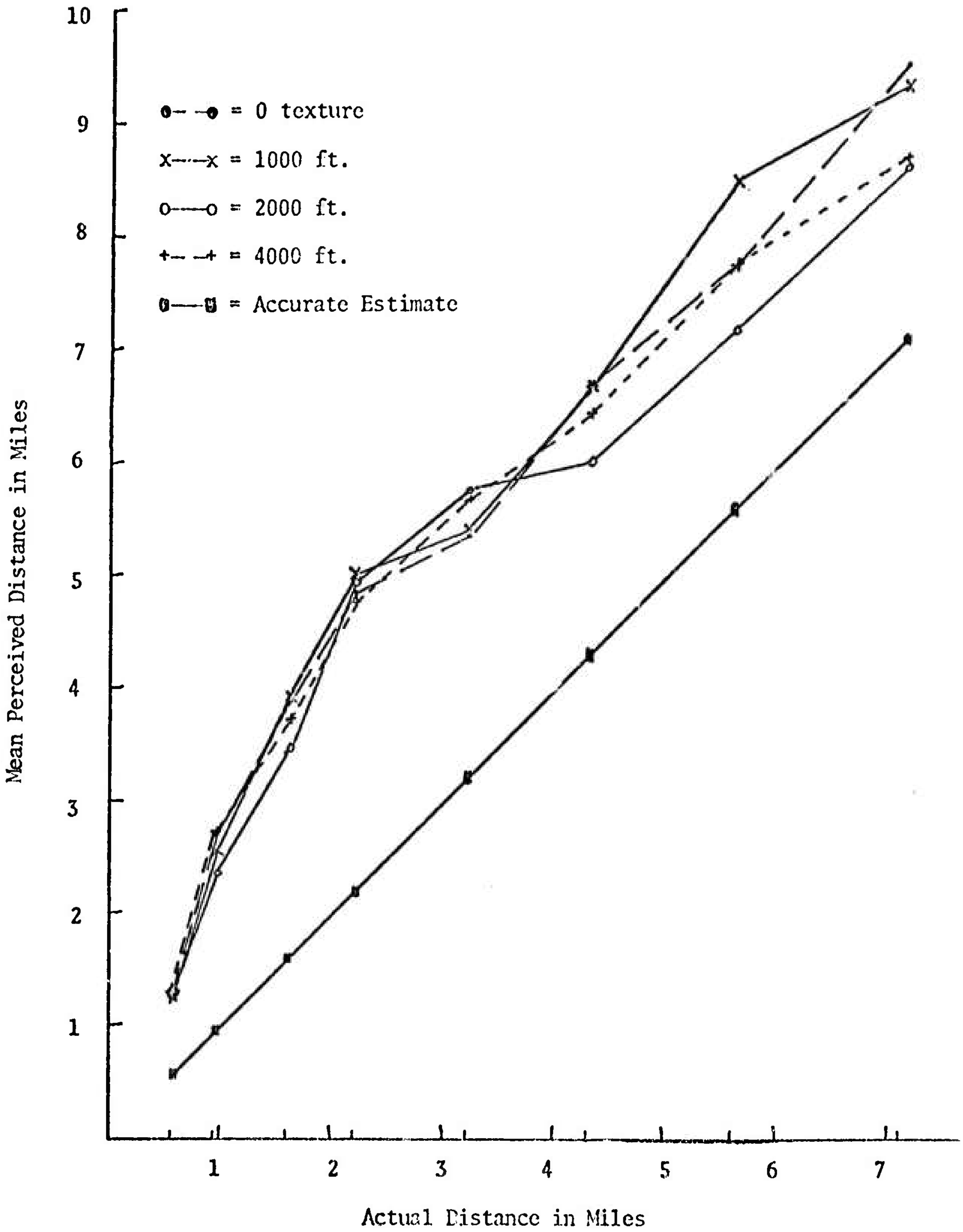

Figure 16. Mean raw score distance estimates for both sequences. Student observers.

TABLE 13

SOURCE TABLE FOR ANALYSIS OF VARIANCE OF

ESTIMATED DISTANCES BY STUDENT OBSERVERS

SOURCES	SS	DF	MS	F	P
Distances	7709.23	7.	1101.23	< 32.47	< .001
Error	9022.69	266.	33.92		
Texture	26.65	3.	8.88	4.99	.003
Error	202.57	114.	1.78		
Groups	58.29	1.	58.30	< 1.	
Error	25390.57	38.	668.17		
Distances x Texture	60.15	21.	2.87	1.48	.074
Error	1540.07	798.	1.93		
Distances x Groups	21.84	7.	3.12	< 1.	
Error	9022.69	266.	33.92		
Texture x Groups	5.61	3.	1.87	1.05	.372
Error	202.57	114.	1.78		
Distances x Texture x Groups	102.68	21.	4.89	2.53	< .001
Error	1540.08	798.	1.93		

TABLE 14

MEAN AND STANDARD DEVIATION OF ESTIMATED DISTANCES OF STUDENT OBSERVERS

		Buildings (mi.)								
		.56	.94	1.6	2.2	3.2	4.3	5.6	7.1	ROW MEAN
1st Sequence	0	1.00 0.55	2.51 2.09	3.59 3.08	4.77 4.47	5.14 4.56	6.76 5.30	7.17 5.33	10.30 12.83	5.15
	1000	1.19 0.93	2.14 1.53	3.73 3.43	4.93 4.15	5.25 3.90	6.09 5.75	8.14 7.09	9.00 7.91	5.06
	2000	1.24 0.74	2.03 1.54	3.26 2.38	4.76 4.49	5.53 5.59	5.92 4.98	6.47 6.70	8.63 7.88	4.73
	4000	1.24 0.86	2.48 1.76	3.06 2.50	4.82 4.76	5.85 4.91	6.56 5.79	7.55 6.05	7.53 10.61	4.89
2nd Sequence	0	1.48 1.05	2.84 2.16	4.17 3.55	4.94 3.98	5.57 5.66	6.69 5.94	8.37 7.78	8.83 7.82	5.36
	1000	1.32 0.83	3.00 2.52	4.07 3.65	5.09 3.90	5.52 4.75	7.25 7.61	8.85 9.68	9.76 8.98	5.61
	2000	1.32 0.87	2.65 2.26	3.68 3.40	5.09 4.63	5.98 5.52	6.16 5.67	7.90 8.72	8.62 8.09	5.17
	4000	1.32 0.85	2.92 2.36	4.35 4.00	4.77 4.06	5.52 4.69	6.35 4.86	8.00 7.72	9.92 9.94	5.39

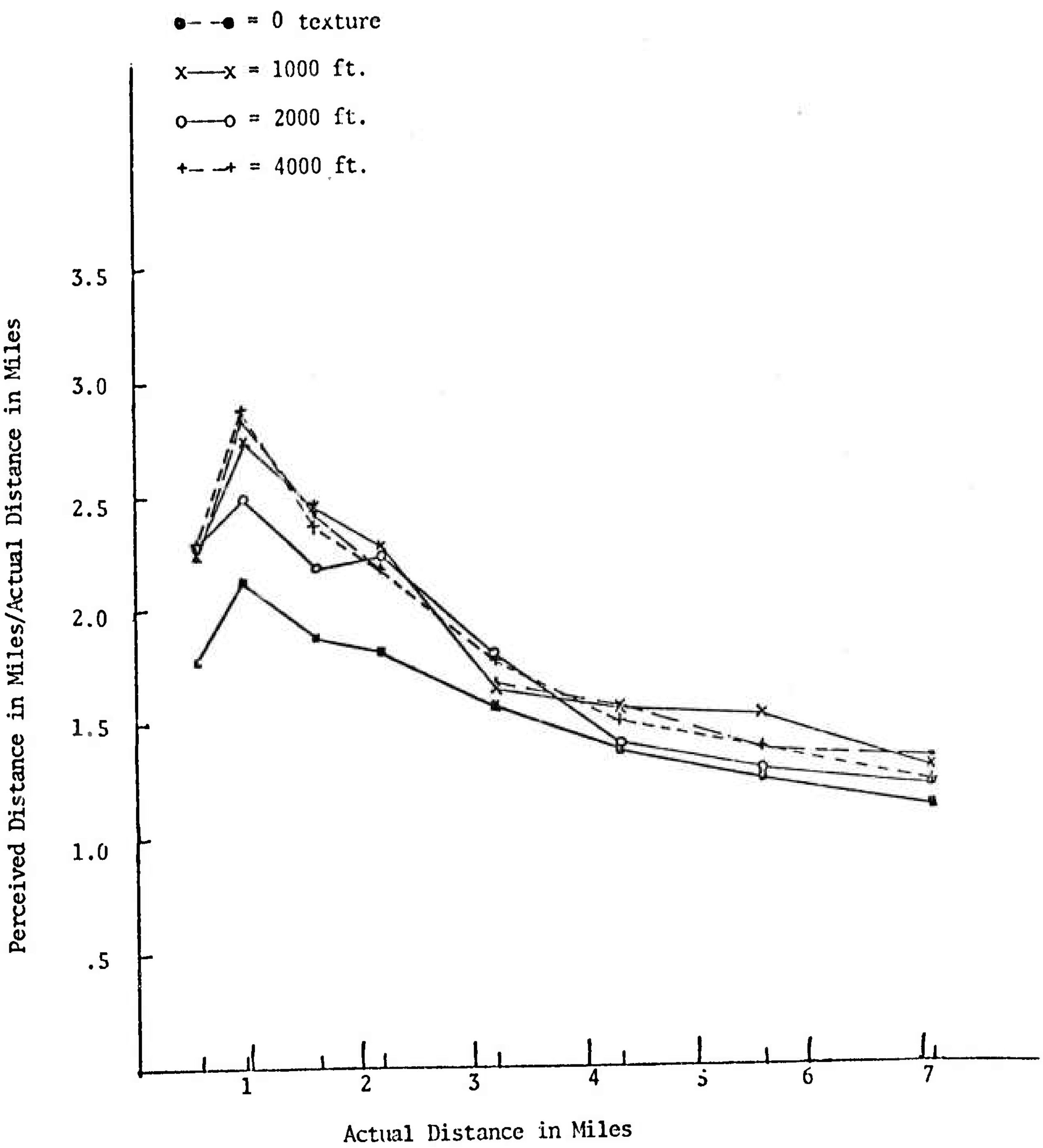

Figure 17. Relative over-estimation of distances in both sequences. Squares indicate responses obtained if subject assumes (or perceives) buildings to be equally spaced at 1, 2, 3, 4, 5, 6, 7, and 8 miles.

similarity in the shapes of the curves suggests that this is the strategy being used. Whether the display appears this way to the subjects, or whether it is a conscious or unconscious assumption on their part is unknown. Except for the distance between buildings 4 and 5 (2.2 miles and 3.2 miles - perceived as .59 miles apart) and the distance between buildings 7 and 8 (5.6 miles and 7.1 miles - perceived as 1.44 miles apart), the perceived distance between buildings is almost constant (1.08 to 1.3 miles). This result is in contrast to the results of Experiment I in which no relation could be demonstrated between actual and perceived distances between buildings. Figure 17 in the present study more closely resembles Figure 9 (air crew observers) than Figure 4 (student observers).

5. A logarithmic transformation was performed on the raw score data to reduce the inhomogeneity of variance across distances (see Table 14). The results of this transformation are presented in Figure 18. As can be seen, the greatest amount of over-estimation occurs on buildings 2-5 (.94 miles to 4.3 miles). These results are in agreement with those obtained in the previous experiment on Aerial Perspective. An analysis of variance using the transformed scores indicated a significant effect of texture size ($F = 5.35$; $p = .002$) (see Table 15). The logarithm of the means and standard deviations are presented in Table 16.
6. A second, relative transformation was performed by taking each datum and dividing it by the mean distance estimate (both sequences) to the farthest building under the no texture condition (9.02 miles). The results of this transformation are presented in Figure 19. Again, the distances to the middle buildings (2-5) show the greatest amount of over-estimation. This is probably due to the tendency of subjects to respond as if the buildings were equally spaced at one mile intervals. Thus, the shorter distances (which are .5 miles apart) are over-estimated to a greater extent than the longer distances (which are 1.0 or 1.5 miles apart).
7. An analysis of variance was performed on the relative transform scores. The results are presented in Table 17. There is a significant difference among the texture conditions ($F = 3.5$; $p = .02$). The differences between sequences was not significant ($F < 1$). The means and standard deviations of the transformed scores are presented in Table 18.
8. Close examination of individual subjects' responses indicated a greater tendency in this experiment over the previous one for subjects to under-estimate the total number of buildings. Several subjects did not discriminate well between the two most distant buildings or between the three buildings at 2.2, 3.2 and 4.3 miles.
9. Comparison of the mean estimates for the no texture condition with the mean estimates for all three texture conditions revealed no significant difference. Apparently, the presence of the texture conditions within the sequence is sufficient to produce more accurate distance estimates than were obtained with the "blank" green fields used in Experiment I.

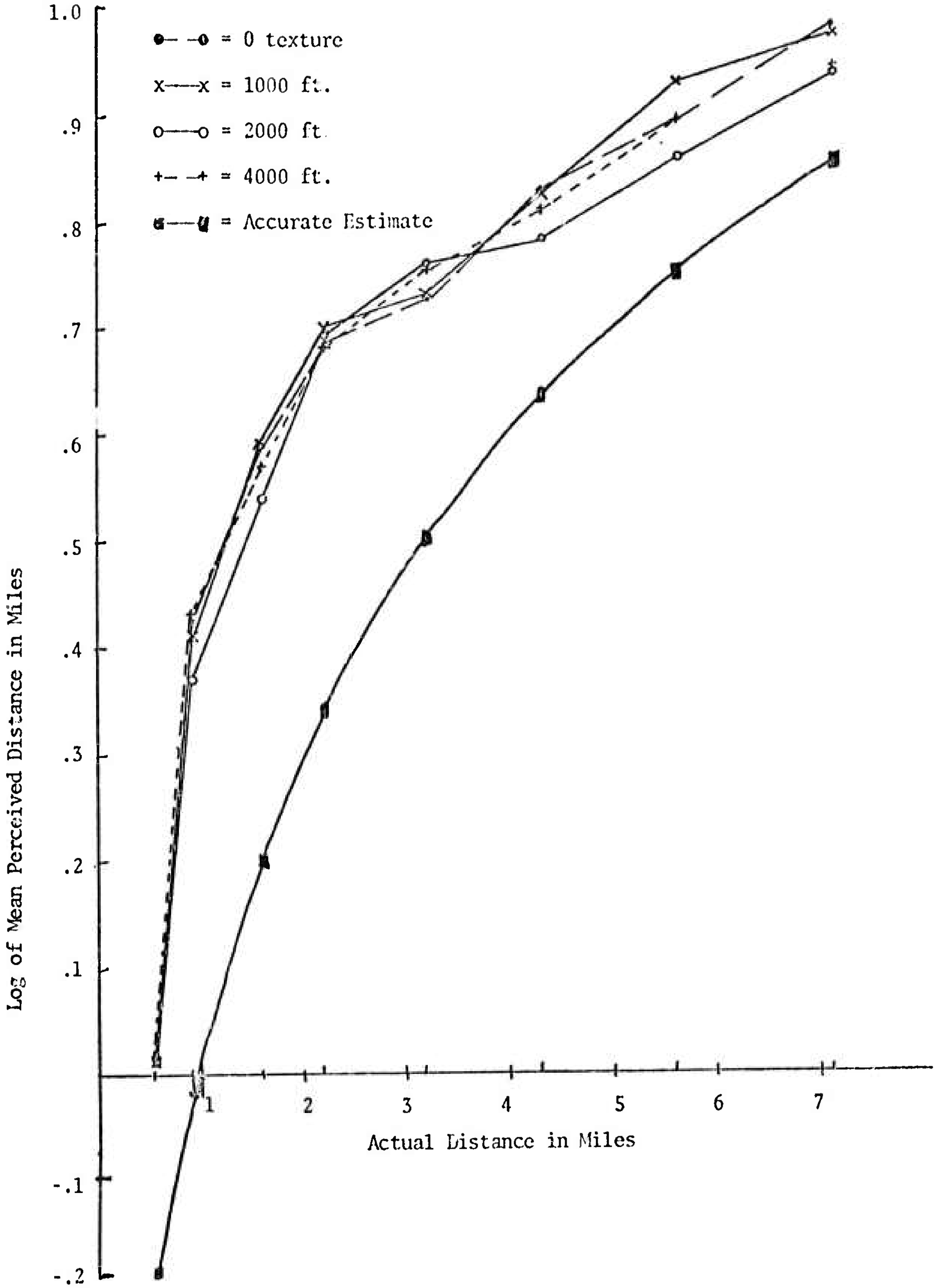

Figure 18. Logarithm of mean perceived distances for both sequences. Student observers.

TABLE 15

ANALYSIS OF VARIANCE OF LOGARITHMIC

TRANSFORMATION OF ESTIMATED DISTANCES FOR STUDENT OBSERVERS

SOURCE	SS	DF	MS	F	P
Distances	36.21	7.	5.17	170.30	< .001
Error	8.08	266.	.03		
Texture	.08	3.	.03	5.35	.002
Error	.57	114.	.005		
Groups	.31	1.	.31	< 1.	
Error	86.38	38.	2.27		
Distances x Texture	.19	21.	.01	2.32	< .001
Error	3.22	798.	.004		
Distances x Groups	.07	7.	.01	< 1.	
Error	8.08	266.	.03		
Texture x Groups	.003	3.	.001	< 1.	
Error	.56	114.	.005		
Distances x Texture x Groups	.24	21.	.01	2.79	< .001
Error	3.22	798.	.004		

TABLE 16

LOGARITHM OF MEAN AND STANDARD DEVIATION OF ESTIMATED DISTANCES OF STUDENT OBSERVERS

		Buildings (mi.)								
		.56	.94	1.6	2.2	3.2	4.3	5.6	7.1	RAW MEAN
1st Sequence	0	0.00	0.40	0.56	0.68	0.71	0.83	0.86	1.01	0.71
		-0.26	0.32	0.49	0.65	0.66	0.73	0.73	1.11	
	1000	0.08	0.33	0.57	0.69	0.72	0.78	0.91	0.95	0.70
		-0.03	0.19	0.54	0.62	0.59	0.76	0.85	0.90	
	2000	0.09	0.31	0.51	0.68	0.74	0.77	0.81	0.94	0.67
		-0.13	0.14	0.38	0.65	0.75	0.70	0.83	0.91	
	4000	0.09	0.40	0.49	0.68	0.77	0.82	0.88	0.88	0.69
		-0.06	0.25	0.40	0.68	0.69	0.76	0.78	1.03	
2nd Sequence	0	0.17	0.45	0.62	0.69	0.75	0.83	0.92	0.95	0.73
		0.02	0.33	0.55	0.60	0.75	0.77	0.89	0.89	
	1000	0.12	0.48	0.61	0.71	0.74	0.86	0.95	0.99	0.75
		-0.08	0.40	0.56	0.59	0.68	0.88	0.99	0.95	
	2000	0.12	0.42	0.57	0.71	0.78	0.79	0.90	0.94	0.71
		-0.06	0.35	0.53	0.67	0.74	0.75	0.94	0.91	
	4000	0.12	0.47	0.64	0.68	0.74	0.80	0.90	1.00	0.73
		-0.07	0.37	0.60	0.61	0.67	0.68	0.89	1.00	

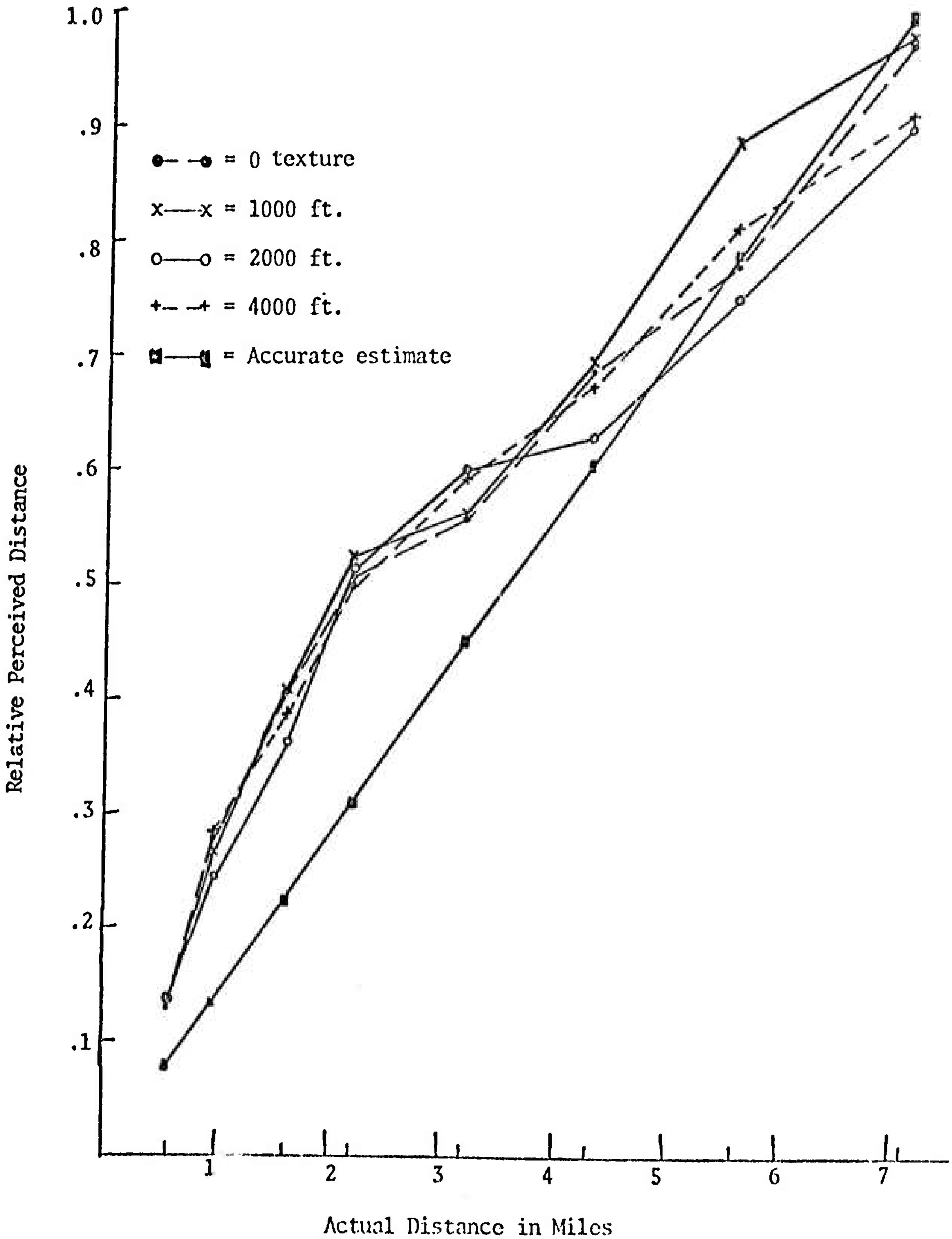

Figure 19. Relative perceived distance (relative to mean for both sequences of 7.1 mile building 0 texture background) for both sequences. Student observers.

TABLE 17

SOURCE TABLE FOR ANALYSIS OF VARIANCE OF RELATIVE

TRANSFORMATION OF DISTANCE ESTIMATES BY STUDENT OBSERVERS

SOURCE	SS	DF	MS	F	P
Distance	82.50	7.	11.78	31.78	< .001
Error	98.66	266.	.37		
Texture	.26	3.	.09	3.5	.018
Error	2.80	114.	.02		
Sequence	.77	1.	.77	< 1.	
Error	277.10	38.	7.29		
Distance x Texture	.61	21.	.03	1.29	.17
Error	18.01	798.	.02		
Distance x Sequence	.30	7.	.04	< 1.	
Error	98.66	266.	.37		
Texture x Sequence	.01	3.	.005	< 1.	
Error	2.80	114.	.024		
Distance x Texture x Sequence	1.02	21.	.05	2.16	.002
Error	18.01	798.	.02		

TABLE 18

MEAN AND STANDARD DEVIATION OF RELATIVE TRANSFORMATION OF ESTIMATED DISTANCES BY STUDENT OBSERVERS

		Buildings (mi.)								
		.56	.94	1.6	2.2	3.2	4.3	5.6	7.1	ROW MEAN
1st Sequence	0	0.10 0.05	0.26 0.21	0.37 0.32	0.49 0.46	0.53 0.47	0.67 0.57	0.69 0.57	1.02 1.36	0.52
	1000	0.12 0.09	0.22 0.16	0.39 0.35	0.51 0.43	0.54 0.40	0.63 0.60	0.85 0.74	0.94 0.82	0.52
	2000	0.13 0.07	0.21 0.16	0.34 0.25	0.49 0.47	0.57 0.58	0.61 0.52	0.67 0.70	0.90 0.82	0.49
	4000	0.13 0.09	0.26 0.18	0.32 0.26	0.50 0.49	0.61 0.51	0.68 0.60	0.78 0.63	0.78 1.10	0.51
2nd Sequence	0	0.15 0.11	0.29 0.22	0.43 0.37	0.51 0.41	0.58 0.59	0.69 0.62	0.87 0.81	0.92 0.81	0.56
	1000	0.13 0.08	0.31 0.26	0.42 0.38	0.53 0.40	0.57 0.49	0.75 0.79	0.92 1.01	1.02 0.93	0.58
	2000	0.13 0.09	0.27 0.23	0.38 0.35	0.53 0.48	0.62 0.57	0.64 0.59	0.82 0.91	0.90 0.84	0.54
	4000	0.13 0.08	0.30 0.24	0.45 0.41	0.49 0.42	0.57 0.49	0.66 0.50	0.83 0.80	1.03 1.03	0.56

10. Comparison of the means for the 0 and 1000 ft. conditions and those for 2000 and 4000 ft. revealed no significant difference between these conditions.

<u>Air Crew Member Observers</u>

The mean raw score estimates for the 10 air crew member observers (ACM) are presented in Figures 20-22. Figures 20 and 21 present the data for the first and second sequences, respectively. Figure 22 presents the means of the two sequences. The results are summarized below:

1. Air crew members over-estimate the distances to all of the buildings. The circled points in Figure 20 indicate the first 8 estimates in the first sequence. These initial responses are the shortest and most accurate estimates for each of the buildings.
2. Although the mean for the 10 observers indicates a general tendency to over-estimate the distances, 4 of the ACM observers under-estimated the distances, particularly to the farther buildings.
3. A comparison of Figures 20 and 21 indicates that ACM's distance judgments increase in the second sequence over the first and become less variable. However, the analysis of variance revealed no significant difference as a function of sequence ($F < 1$; see Table 19). (For the means and standard deviations of both sequences, see Table 20.)
4. Although there is a significant effect of texture in both sequences ($F = 7.64$, $p < .001$; $F = 3.92$, $p < .02$; see Table 19), there are no obvious trends in the first sequence due to an interaction of texture and distance ($F = 5.47$, $p < .001$) which did not occur in the second sequence, but did occur in the overall ANOVA ($F = 5.1$, $p < .001$; see Table 19). In the second sequence the no texture condition produced a greater over-estimation of distance to the farthest three buildings (4.3, 5.6 and 7.1 mi.) than the three texture conditions, which did not appear to differ from one another. There was no observable effect of texture on the responses to the first five buildings (see Figure 21).
5. Figure 23 indicates the relative over-estimation of distances to the eight buildings for the four texture conditions taken from the data presented in Figure 22. The greatest over-estimation occurred at the shorter distances with the no texture and 4000 ft. texture conditions. The mean perceived distance between the first (.56 mi.) and second (.94 mi.) buildings for the no texture and 4000 ft. texture conditions was apparently 1.5 mi. for both. (While subjects were not asked to estimate distances between comparison buildings, the difference between the estimates to the first and second buildings was 1.5 mi. for the two conditions.) For the buildings at 4.3 and 5.6 mi. the no texture condition produced the greatest over-estimation. The squares indicate the results that would have been obtained if the air crew members assumed that the buildings were equally spaced at one mile intervals from one to eight miles. This curve lies virtually on top of the curves for the actual data, suggesting that ACM's were assuming that the buildings were equally

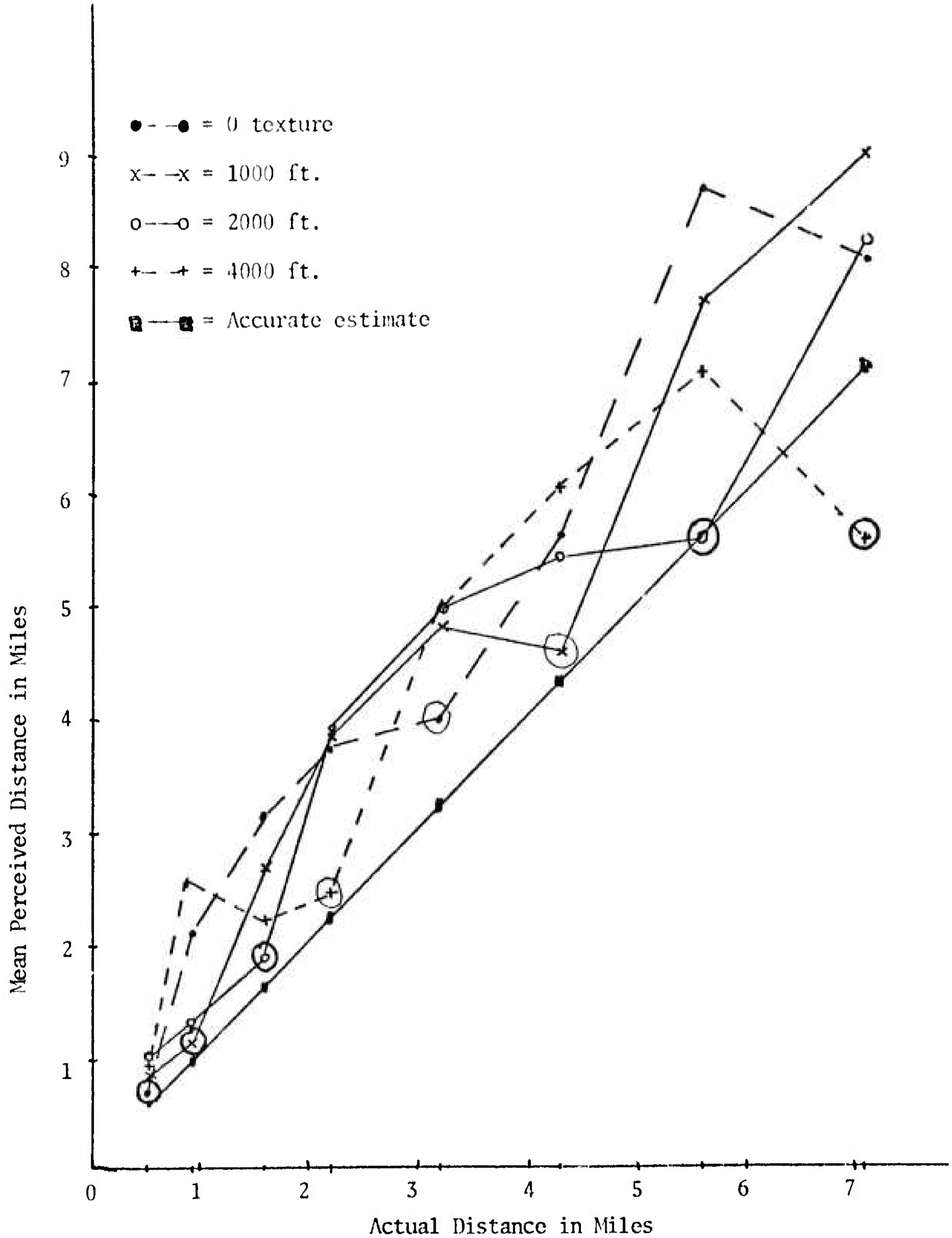

Figure 20. Mean raw score distance estimates for the first sequence. Air crew member observers. Circled points indicate first eight responses.

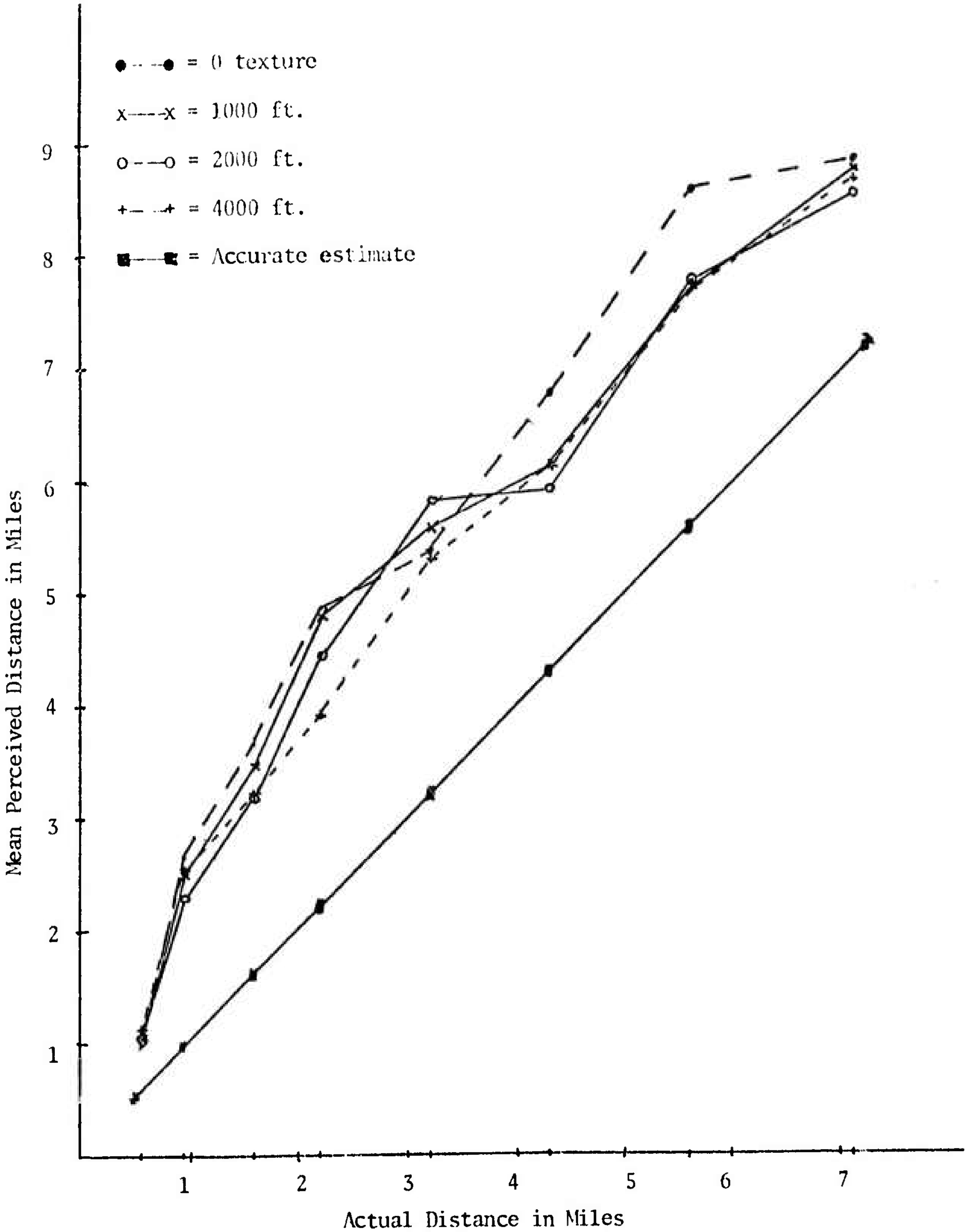

Figure 21. Mean raw score distance estimates for the second sequence. Air crew member observers.

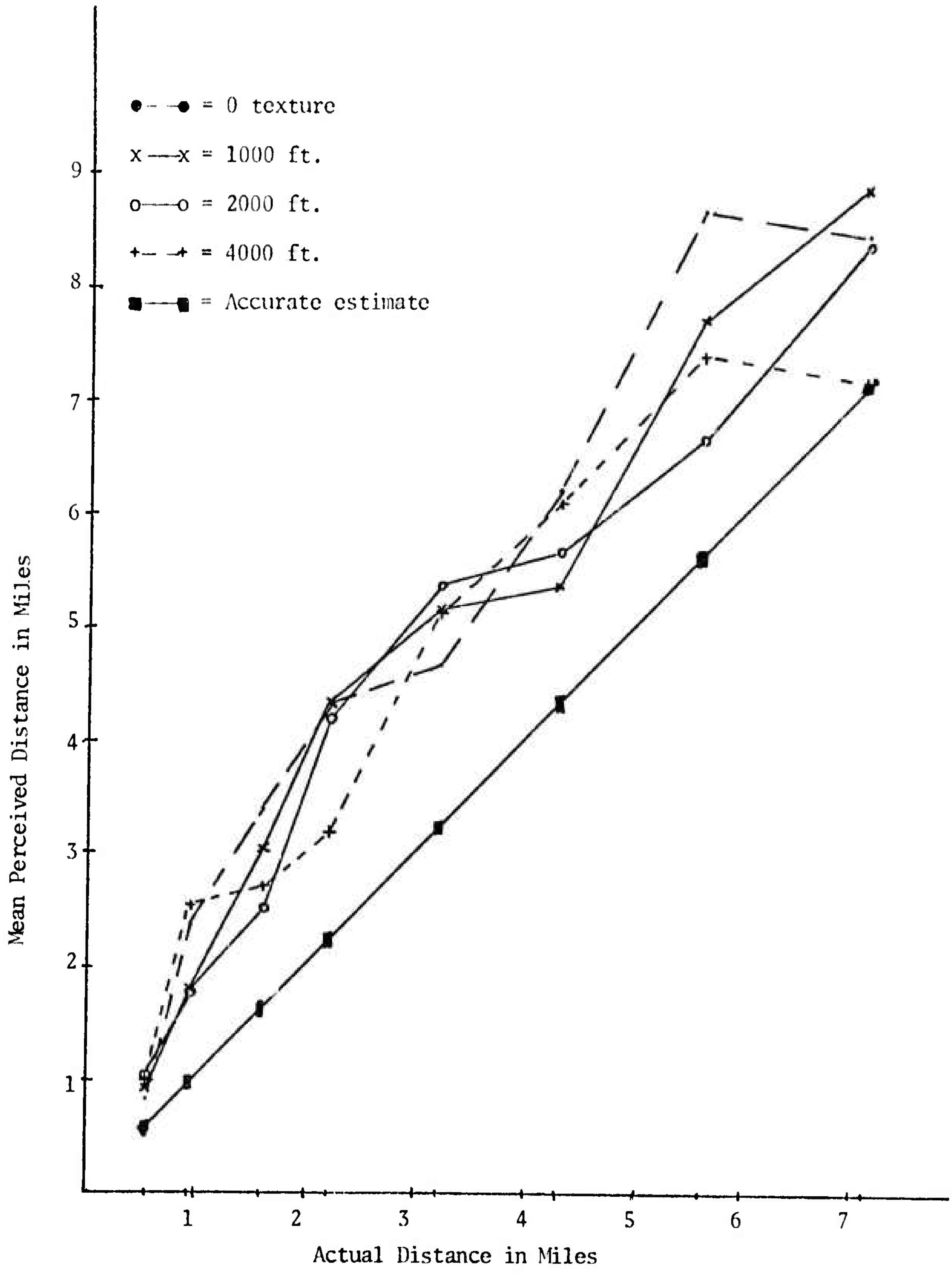

Figure 22. Mean raw score distance estimates for both sequences. Air crew member observers.

TABLE 19

SOURCE TABLE FOR ANALYSIS OF VARIANCE

OF ESTIMATED DISTANCES BY AIR CREW MEMBER OBSERVERS

SOURCES	SS	DF	MS	F	P
Distances	3738.14	7.	534.02	36.67	< 0.001
Error	1834.62	126.	14.56		
Texture	21.51	3.	7.17	11.21	< 0.001
Error	34.53	54.	.64		
Groups	96.45	1.	96.45	< 1.	
Error	4916.74	18.	273.15		
Distances x Texture	104.43	21.	4.97	5.10	< 0.001
Error	368.43	378.	.97		
Distances x Groups	10.29	7.	1.47	< 1.	
Error	1834.62	126.	14.56		
Texture x Groups	1.02	3.	.34	< 1.	
Error	34.53	54.	.64		
Distances x Texture x Groups	67.50	21.	3.21	3.29	< 0.001
Error	368.43	378.	.97		

TABLE 20

MEAN AND STANDARD DEVIATION OF ESTIMATED DISTANCES BY AIR CREW MEMBER OBSERVERS

Buildings (mi.)

		.56	.94	1.6	2.2	3.2	4.3	5.6	7.1	ROW MEAN
1st Sequence	0	0.70	2.10	3.14	3.76	4.00	5.16	8.77	8.09	4.52
		0.14	1.43	1.92	2.52	2.68	3.36	5.63	5.16	
	1000	0.83	1.13	2.67	3.82	4.80	4.59	7.70	9.00	4.31
		0.37	0.43	2.00	2.83	3.36	3.25	5.49	5.42	
	2000	1.00	1.30	1.86	3.91	4.95	5.42	5.56	8.22	4.03
		0.32	0.77	1.01	3.35	3.32	4.35	4.15	5.61	
	4000	0.91	2.55	2.24	2.46	4.97	6.06	7.08	5.59	3.98
		0.36	2.06	1.57	1.84	3.59	4.25	5.04	3.54	
2nd Sequence	0	0.97	2.64	3.68	4.87	5.37	6.79	8.63	8.87	5.22
		0.34	1.42	2.01	3.35	3.36	4.54	4.90	5.60	
	1000	1.00	2.49	3.45	4.82	5.59	6.16	7.74	8.79	5.00
		0.35	1.33	1.67	3.56	4.28	4.08	5.40	5.91	
	2000	1.06	2.28	3.17	4.44	5.81	5.91	7.80	8.58	4.88
		0.34	1.12	2.14	2.91	4.19	3.97	5.86	5.71	
	4000	1.13	2.52	3.20	3.94	5.36	6.14	7.72	8.73	4.84
		0.47	1.29	1.81	2.61	3.48	3.61	5.52	6.06	

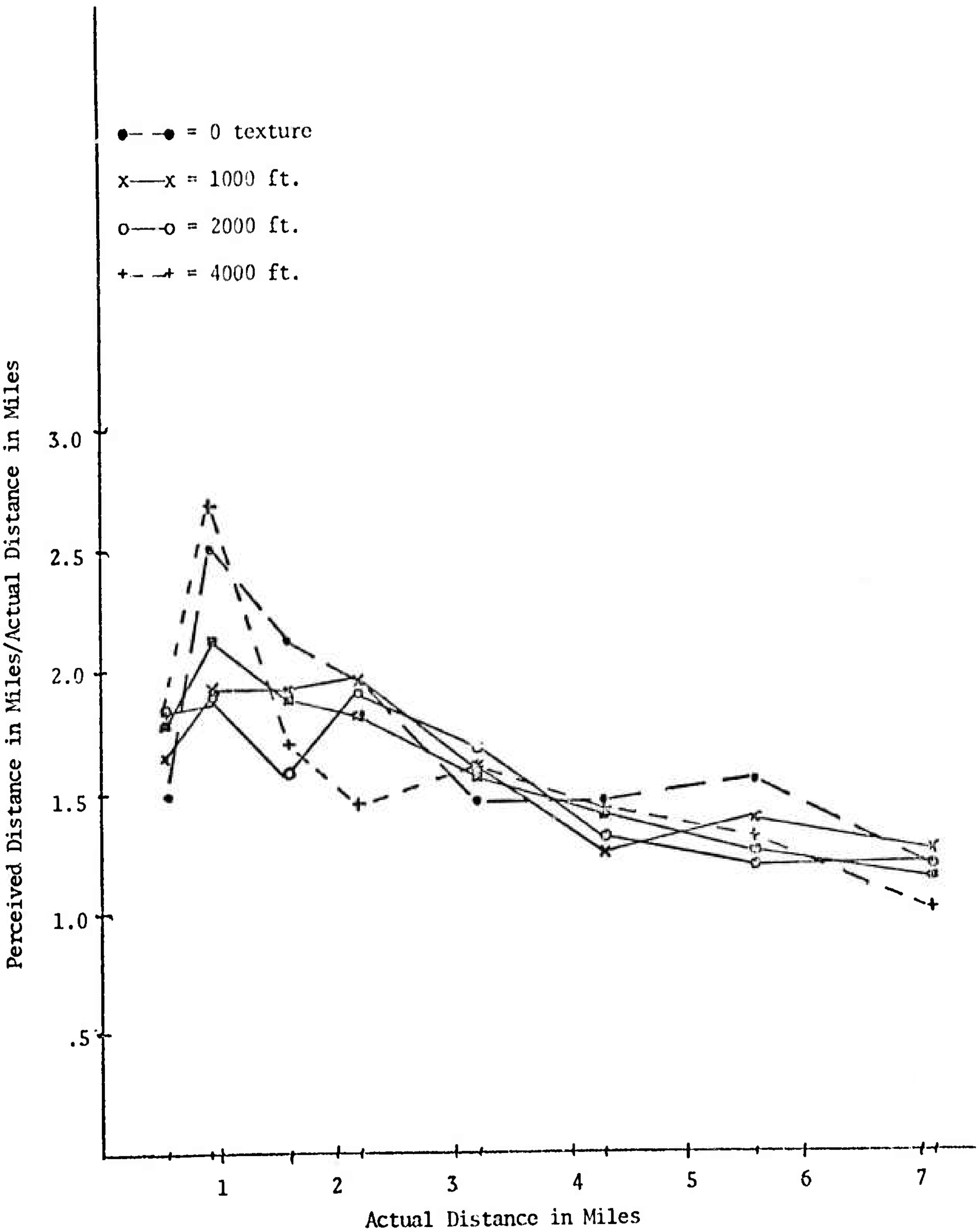

Figure 23. Relative over-estimation of distances in both sequences. Squares indicate responses obtained if subject assumes (or perceives) buildings to be equally spaced at 1, 2, 3, 4, 5, 6, 7, and 8 miles. Air crew member observers.

spaced; except for the distance between the first and second building for the no texture and 4000 ft. texture conditions as noted above.

6. A logarithmic transformation was performed on the raw score estimates in an effort to reduce the inhomogeneity of variance (note standard deviation in Table 8 increases with the mean, Winer, 1962, p. 219). The results of this transformation are presented in Figure 24. The greatest over-estimation of distance occurred for the buildings at .94, 1.6 and 2.2 miles. There is no obvious difference as a function of texture, although an analysis of variance using the transformed scores indicated a statistically significant effect ($F = 11.5$, $p < .001$; see Table 21). (For the logarithm of the means and standard deviations, see Table 22.)
7. A relative transformation was also performed on the original data. The distance estimate to each building under each texture condition was divided by the mean distance estimate to the farthest building (7.1 mi.) with no texture, for both sequences (8.44 mi.). The results of this transformation are presented in Figure 25. The slope of the relative data closely approximates that of the actual distances with the same transformation applied (actual distance/7.1 mi.). The no texture condition appears to have produced the most accurate relative distance scores.
8. An analysis of variance using the relatively transformed scores indicated a significant effect of texture across both sequences ($F = 11.1$, $p < .001$; see Table 23). There was no significant difference between the sequences ($F < 1$). The means and standard deviations of the relatively transformed scores are presented in Table 24.
9. Comparison of the present data with those obtained for ACM's in Experiment I on Aerial Perspective indicates a greater tendency, in the present experiment, to over-estimate the distances to the farther buildings. The distances to the near buildings were over-estimated less in the present experiment. For ACM's the addition of a textured background appears to have a shortening effect on shorter distances and a lengthening effect on the longer distances. It is not clear whether this effect is a true result of the addition of texture, or a result of intersubject variability between the two groups of ACM's.

Comparison of Student and Air Crew Observers

A comparison of Figures 14-19 (students) with Figures 20-25 (air crew member observers) reveals several points.

1. Air crew member observers' estimates were more accurate than students' (compare Figures 14-16 with Figures 20-22). This is particularly true of the comparison between the first eight estimates in the first sequence for both groups (see circled points in Figures 14 and 20). These initial estimates were the most accurate of the ACM's which may indicate a change of criterion over trials.

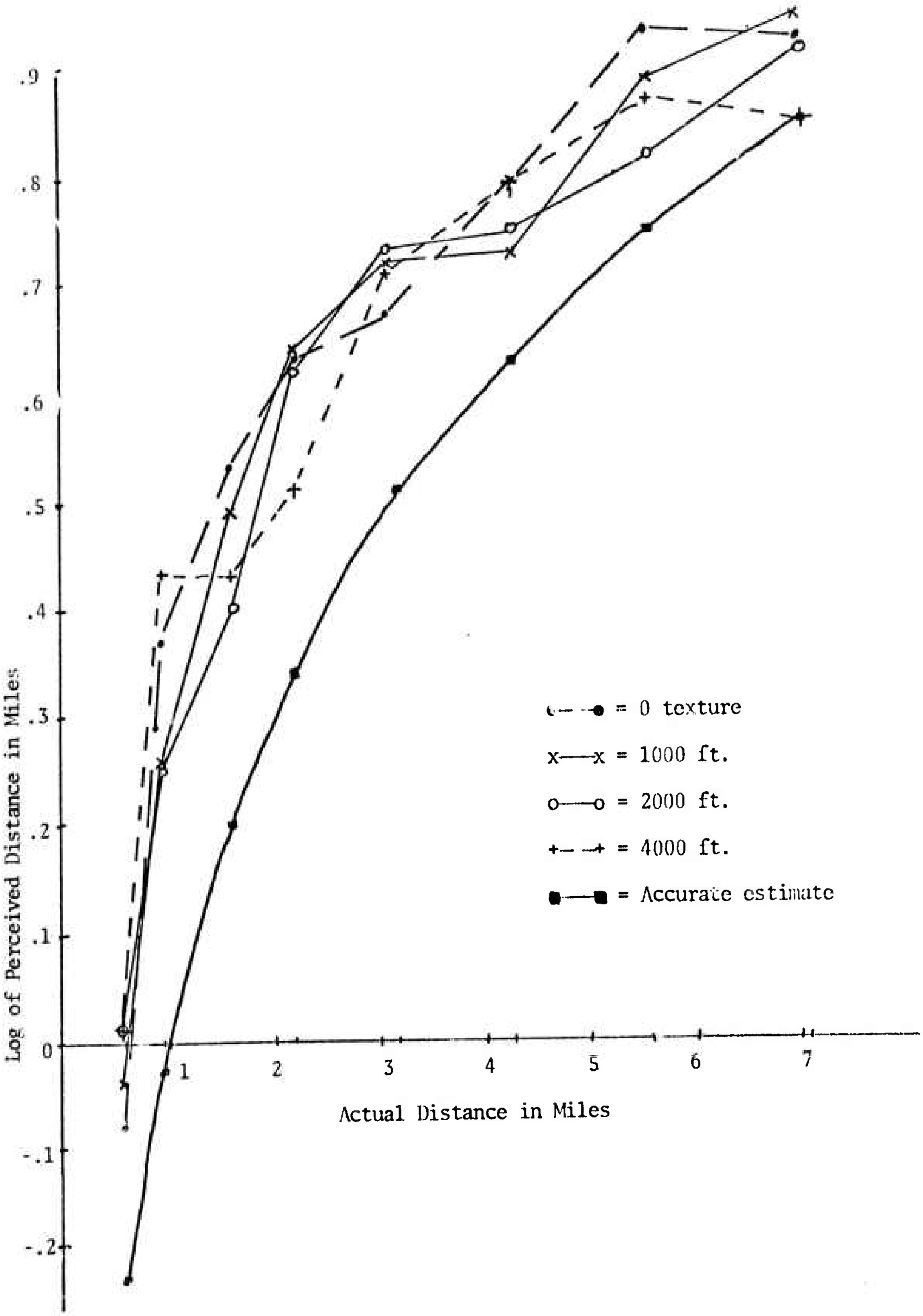

Figure 24. Logarithm of mean perceived distances for both sequences. Air crew member observers.

TABLE 21

ANALYSIS OF VARIANCE OF LOGARITHMIC TRANSFORMATION

OF ESTIMATED DISTANCES FOR AIR CREW MEMBER OBSERVERS

SOURCES	SS	DF	MS	F	P
Distances	24.26	7.	3.47	139.83	< 0.001
Error	3.12	126.	.02		
Texture	.11	3.	.04	11.50	< 0.001
Error	.17	54.	.003		
Groups	.77	1.	.79	< 1.	
Error	23.65	18.	1.31		
Distances x Texture	.64	21.	.03	7.40	< 0.001
Error	1.56	378.	.004		
Distances x Groups	.10	7.	.01	< 1.	
Error	3.12	126.	.02		
Texture x Groups	.01	3.	.002	< 1.	
Error	.17	54.	.003		
Distances x Texture x Groups	.30	21.	.01	3.49	< 0.001
Error	1.56	378.	.004		

TABLE 22

LOGARITHM OF MEAN AND STANDARD DEVIATION OF ESTIMATED DISTANCES OF AIR CREW MEMBER OBSERVERS

		Buildings (mi.)								
		.56	.94	1.6	2.2	3.2	4.3	5.6	7.1	ROW MEAN
1st Sequence	0	-0.15	0.32	0.50	0.58	0.60	0.75	0.94	0.91	0.65
		-0.84	0.16	0.28	0.40	0.43	0.53	0.75	0.71	
	1000	-0.08	0.05	0.45	0.58	0.68	0.66	0.89	0.95	0.63
		-0.42	-0.36	0.30	0.45	0.55	0.51	0.74	0.73	
	2000	0.002	0.12	0.27	0.59	0.69	0.73	0.75	0.92	0.60
		-0.49	-0.11	0.01	0.53	0.52	0.64	0.62	0.75	
	4000	-0.04	0.41	0.35	0.39	0.70	0.78	0.85	0.75	0.60
		-0.44	0.31	0.20	0.27	0.56	0.63	0.70	0.55	
2nd Sequence	0	-0.01	0.42	0.57	0.69	0.73	0.83	0.94	0.95	0.72
		-0.47	0.15	0.30	0.53	0.53	0.66	0.69	0.75	
	1000	0.003	0.40	0.54	0.68	0.75	0.79	0.89	0.94	0.70
		-0.45	0.13	0.22	0.55	0.63	0.61	0.73	0.77	
	2000	0.02	0.36	0.50	0.65	0.76	0.77	0.89	0.93	0.69
		-0.47	0.05	0.33	0.47	0.62	0.60	0.77	0.76	
	4000	0.05	0.40	0.51	0.60	0.73	0.79	0.89	0.94	0.68
		-0.32	0.11	0.26	0.42	0.54	0.56	0.74	0.78	

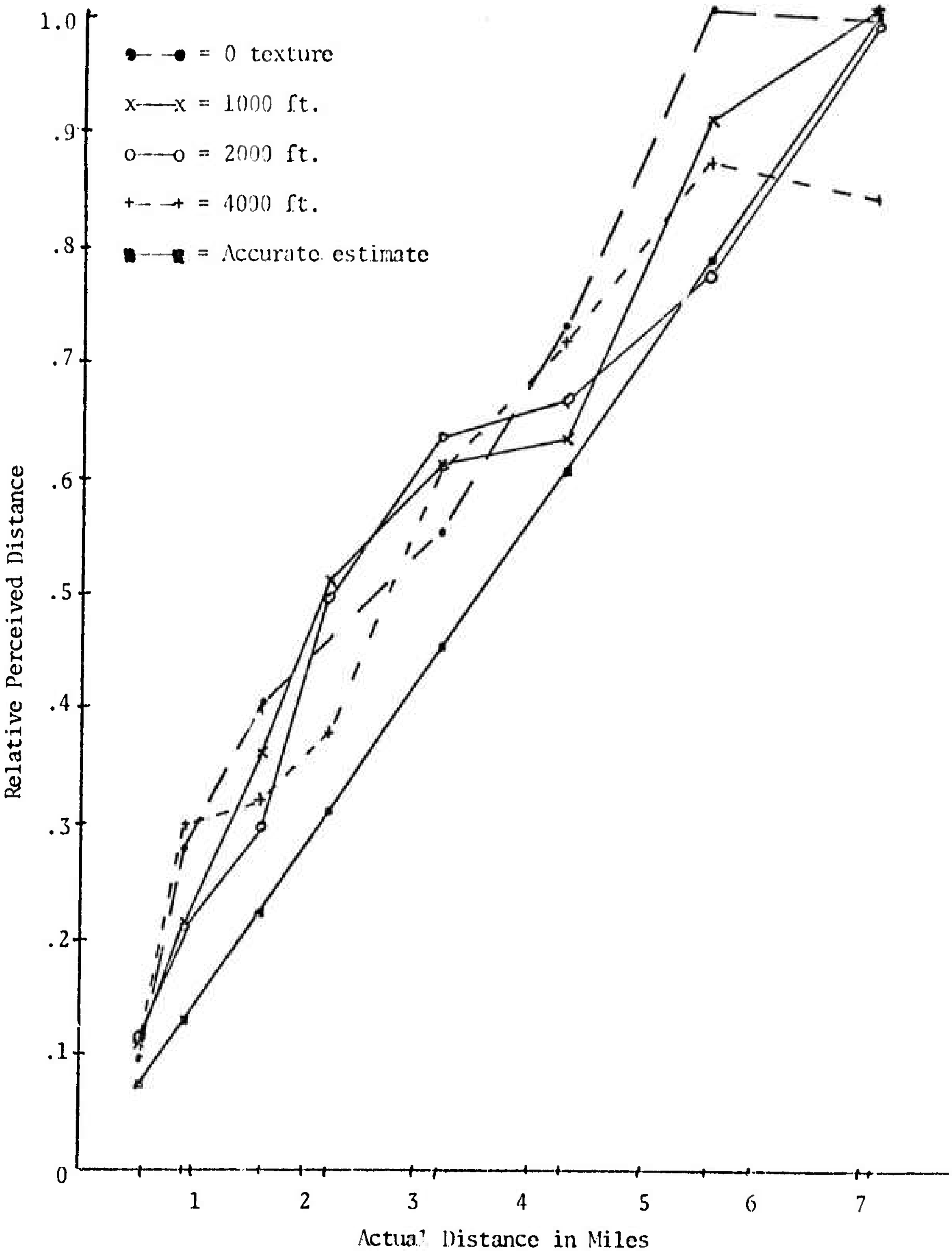

Figure 25. Relative perceived distance (relative to mean for both sequences of 7.1 mile building on 0 texture background) for both sequences. Air crew member observers.

TABLE 23

SOURCE TABLE FOR ANALYSIS OF VARIANCE OF RELATIVE

TRANSFORMATION OF DISTANCE ESTIMATES BY AIR CREW MEMBER OBSERVERS

SOURCES	SS	DF	MS	F	P
Distance	51.98	7.	7.43	36.68	< 0.001
Error	25.50	126.	.20		
Texture	.29	3.	.10	11.19	< 0.001
Error	.48	54.	.01		
Sequence	1.34	1.	1.34	< 1.	
Error	68.37	18.	3.80		
Distance x Texture	1.45	21.	.07	5.10	< 0.001
Error	5.12	378.	.01		
Distance x Sequence	.14	7.	.02	< 1.	
Error	25.50	126.	.20		
Texture x Sequence	.01	3.	.005	< 1.	
Error	.48	54.	.009		
Distance x Texture x Sequence	.93	21.	.04	3.29	< 0.001
Error	5.12	378.	.01		

TABLE 24

MEAN AND STANDARD DEVIATION OF RELATIVE TRANSFORMATION OF ESTIMATED DISTANCES BY AIR CREW MEMBER OBSERVERS

		Buildings (mi.)								
		.56	.94	1.6	2.2	3.2	4.3	5.6	7.1	ROW MEAN
2nd Sequence	0	0.08	0.24	0.37	0.44	0.47	0.66	1.03	0.95	0.53
		0.01	0.17	0.22	0.29	0.31	0.39	0.66	0.60	
	1000	0.09	0.13	0.31	0.45	0.56	0.54	0.90	1.06	0.50
		0.04	0.05	0.23	0.33	0.39	0.38	0.64	0.63	
	2000	0.11	0.15	0.22	0.46	0.58	0.64	0.65	0.97	0.47
		0.03	0.09	0.12	0.39	0.39	0.51	0.49	0.66	
	4000	0.10	0.30	0.26	0.29	0.58	0.71	0.83	0.65	0.47
		0.04	0.24	0.18	0.21	0.42	0.50	0.59	0.41	
1st Sequence	0	0.11	0.31	0.43	0.57	0.63	0.80	1.01	1.04	0.61
		0.04	0.16	0.23	0.39	0.39	0.53	0.57	0.66	
	1000	0.11	0.29	0.40	0.56	0.66	0.72	0.91	1.03	0.59
		0.04	0.15	0.19	0.42	0.50	0.48	0.63	0.69	
	2000	0.12	0.26	0.37	0.52	0.68	0.69	0.92	1.01	0.57
		0.04	0.13	0.25	0.34	0.49	0.46	0.69	0.67	
	4000	0.13	0.29	0.37	0.46	0.63	0.72	0.91	1.02	0.57
		0.05	0.15	0.21	0.30	0.41	0.42	0.65	0.71	

2. A similar change in criterion may also occur in student observers since students' distance estimates were more accurate in the first sequence than the second (see Figures 14 and 15). Air crew members also tended to increase their distance estimates from the first to the second sequence (see Figures 20 and 21).
3. A comparison of mean raw score estimates over both sequences for students and ACM observers (Figures 15 and 22) indicates students over-estimate the distance to the buildings at .94, 1.6, 2.2, 3.2 and 4.3 miles more than ACM observers.
4. A study of the relative over-estimation of distance in both sequences for students and ACM observers (Figures 17 and 23) reveals that students exhibited greater relative over-estimations than ACM observers for the buildings at 0.56, 0.94, 1.6, 2.2, 3.2 and 4.3 miles. While the curve for expected results (if subjects assumed that the buildings were equally spaced from one to eight miles) completely overlaps the ACM data, it is consistently lower than the student data. ACM observers showed a greater over-estimation of the distance to the building at 0.94 mi. under the no texture and 4000 ft. texture conditions than to any other building for any other texture condition (see Figure 23).
5. Comparison of Figures 15 and 21, representing the mean raw score distance estimates over the second sequence, indicates a similarity in the shapes of the curves for the 2000 ft. texture condition for the students and ACM's. However, the curve for the 2000 ft. condition for the students exhibits greater over-estimation than the same curve for the ACM's.
6. There is a similar correspondence between students' and ACM observers' raw score distance estimates in the second sequence for the buildings at 4.3, 5.6 and 7.1 miles (see Figures 15 and 21).
7. Examination of Tables 13 and 18 (mean and standard deviation of original estimates) indicates that inter-subject variability is lower among ACM observers than students. The wide variability, seen in Figure 19, of responses of ACM observers over the first sequence is seen in the significant interaction of distance and texture in the first sequence ($F = 5.47$, $p < .001$). This interaction was not significant for the second sequence.
8. A comparison of the means for the two sequences (Figures 16 and 22) for the last 3 buildings reveals that the 0 texture condition produced the greatest over-estimation among ACM's, whereas the 1000 ft. texture condition produced the greatest over-estimation among students.
9. Examination of individual estimates indicates that nearly the same proportion of students (11 over-estimate/9 under-estimate), as air crew members (6 over-estimate/4 under-estimate) over-estimate the distances.

DISCUSSION

As the results of the two experiments are somewhat different, they will be discussed separately.

Aerial Perspective Factor

Student Observers. Aerial Perspective Factor was used as a cue to distance by the student observers. The estimates of distance to the farthest three buildings (4.3, 5.6 and 7.1 mi.) were more influenced by the level of APF than the estimates of distance to the first five buildings (see Figure 3). This result was expected. Due to the geometric progression of the distances, there was a greater relative blurring of the last three buildings than the first five. The last two buildings are only one raster line high and the density of the APF at that distance was sufficient to affect the actual visibility of these buildings. In addition, the first four buildings (.56 - 2.2 mi.) may have appeared even closer with the higher APF levels because they were not in the haze. For the 0 APF level, the slant range to the 0.5 fading point includes the fourth building (3.2 mi.), but not the third (2.2 mi.).

For student observers, there is a somewhat greater difference between the infinity condition (no APF) and the other three APF levels than between any of the other levels. This would indicate that the presence of the APF per se is more important than the specific level. This result was not surprising as the difference in levels of APF was not obvious, except for the farthest buildings. The no APF level condition, however, was readily discriminable from any of the APF conditions. The subjects' responses apparently reflected the discriminability of the stimulus conditions.

Air Crew Member Observers. Air crew members used the Aerial Perspective Factor as a cue to distance in the first sequence, but not in the second. There are two possible explanations for this result. The first involves the difference between perceived and estimated distances which is discussed below. The second is related to distance estimation, but involves the motivation and strategy used by the ACM. From comments expressed by the subjects, it was concluded that, while ACM noticed the change in APF level, they chose to ignore it and based their judgments on the relative size of the buildings. The difference between the two sequences is probably due to the lack of reliable recognition of the buildings during the first sequence. A building may have been confused with one nearer or farther away, creating the impression that the APF was a significant factor. The use of a between-subjects experimental design could tend to increase the differences as a function of

APF in experienced observers as a single observer would not be exposed to more than one level and would, therefore, be less likely to ignore the visibility cue. We also suspected that air crew members are more likely than students to be concerned with being "right," despite our instructions to tell the experimenter the apparent distance of the building within the display. ACM appeared to be more conscious of being consistent in their responses than students. The amount of experience of the ACM was probably important in their tendency to discount the changes in APF level in making their responses. Air crew members are more aware than the average student that objects do not change their actual distance as a function of visibility. Therefore, the APF may not have been ignored deliberately and at a conscious level. Again, the use of a between-subjects design would have minimized this problem.

Texture

The results of the analysis of variance presented in Tables 13 and 19 indicate that different sizes of a textured background produce statistically different estimates of distances to objects within a complex display. This result was obtained for both student and air crew members. However, examination of Figures 14-16 and 20-22 reveals only small observable differences between the texture conditions for both groups. For ACM in particular (see Figure 21) most of the variance is probably accounted for by the no texture-texture difference rather than the size of the texture itself. Texture size per se appears to be a more relevant variable for student observers than for ACM in the second sequence (see Figure 15).

All directly observable texture effects are on the three buildings farthest from the standard (4.3, 5.6 and 7.1 mi.). The reason for this is not clear. The texture patterns are different enough from one another that it would be highly improbable that a subject could reliably identify a particular location from one pattern to the next and associate a particular building with that location. In addition, subjects were instructed to indicate how far away the buildings appeared to be. This point was emphasized. While there was some aerial perspective factor (APF) in the display, the level was the same for all texture conditions. On the other hand, the APF was the only cue to distance, other than relative size, for the no texture condition. The APF may, therefore, account for the longer estimates to the far buildings with no textured background by ACM. The relative lack of discriminability of the last three buildings may also play a role. Relative size and position in the field are more difficult to discriminate with the farther targets, which are smaller and more closely grouped than those in the foreground. Any cue is more likely to be used at these far distances. Attempted identification of individual buildings by size or position may be used at shorter distances.

In this experiment on texture students and air crew observers gave comparable results, in contrast to Experiment I - Aerial Perspective wherein students grossly overestimated distances. The addition of a textured background significantly reduced the distance estimates of naive observers. It is unlikely that this result is due entirely to intersubject variability as no student in the present study gave a response greater than 20 mi., whereas several students in the first experiment gave

estimates of 20-50 mi. The addition of a textured background to 75% of the stimuli also reduced estimates on the plain or no texture condition, at least for the student observers. This is most probably due to the fact that each subject saw all backgrounds. As explained above, had we used a between groups design, larger differences as a function of texture would probably have been obtained. However, difficulty in obtaining large groups of subjects made the within subjects design necessary in both experiments.

The results for air crew members did not show a significant change with the addition of a textured background; but their responses were more accurate in Experiment 1 than the students' to begin with. The addition of texture did reduce the large over-estimation of distance to the first three buildings (.56, .94 and 1.6 mi.) by ACM found in the previous experiment (compare Figure 9 and Figure 23). This result may be due to inter-subject variability, but the larger over-estimation of distance to these buildings in the present experiment for the no texture and 4000 ft. texture (which has large unpatterned areas in the foreground) suggests that the texture itself has an effect at the closer distances for ACM.

Texture vs. Linear Perspective

Comparing the stimuli for the second experiment with those used in Experiment 1 we can see that the addition of the textured background has also added linear perspective cues and that the number of added lines, or perspective cues, is determined by the size of the texture pattern. That is, there are twice as many "edges" in the 1000 ft. condition. Is it possible that the improved performance of the student observers is due to the addition of linear perspective cues rather than the texture? This is a somewhat difficult question to answer. Braunstein (1968) conducted a series of experiments and concluded that a texture gradient composed of random dots was not sufficient to produce accurate slant or depth perception and that perspective was probably the principle source of information about depth. Braunstein, however, was concerned with the veridical perception of the slant of a plane under restricted viewing conditions and the same processes may not be operating in the distance estimation task used here.

Gibson (1959) performed an experiment involving the perception of slant with a regular and irregular texture gradient. The regular texture gradient was composed of rectangles arranged like a brick wall; the irregular pattern was "fibrous" with no consistent sizes or shapes. While all slant angles were under-estimated, the regular pattern produced greater estimates of slant than the irregular pattern for equal actual slants. Gibson points out that the linear perspective cues in the regular pattern may have been the important factor in the results, but again, perceived slant and distance estimation may not involve the same information processing.

In a study of perceived distance, Wohlwill (1962) compared the effects of random and non-random rectangular texture of high and low density. Although there were an equal number of "edges" in the random and non-random conditions, Wohlwill assumed that the non-random pattern had more

linear perspective than the random condition due to the more linear arrangement of the texture elements. The over-estimation of "distance-to-the-midpoint" of the space between two targets was greater for the non-random and high density texture conditions. In both Gibson's (1950) and Wohlwill's (1962) experiments, the regular patterns with more linear perspective cues produced greater depth or longer distance estimates than low density random patterns.

These results would lead to the prediction of longer distance estimates for the 1000 ft. texture condition in the present experiment. This prediction was fairly accurate for the student observers (see Figure 15), but not for the air crew members (see Figure 21). Air crew members tended to consider all texture conditions as equal and different only from the no texture condition. As mentioned above, this grouping of texture responses may be due to the within-subjects design of the experiment.

Estimation of Distance

In both experiments the distances to all the buildings were over-estimated by most observers. The distances to the buildings at .56, .94, 1.6 and 2.2 miles were over-estimated more than the others, on a relative scale. Since this result was found in both experiments it is probably independent of aerial perspective or texture conditions, but is related to the general problem of absolute distance estimation. Although there has not been a great deal of research concerning absolute (rather than relative) distance estimation, some of the important variables are relative size, assumed size, height in the field, texture and linear perspective. Stimulus sequence and scaling effects and the problem of perceived as opposed to estimated distance may also be important.

Perceived vs. Estimated Distance. The distinction between perceived and estimated distance was drawn by Hering and was further elucidated by Gilinsky (1951). Perceived distance is defined as a phenomenal or "what does it look like" distance, while estimated distance includes a correction factor derived from past experience or training that produces a better judgment of true distance. In both experiments subjects were asked to give a perceived distance. From the numerical results and the comments of the subjects it was clear that in spite of the instructions, subjects were attempting to "figure out" the actual distances. In the first experiment air crew members indicated that although they noticed the change in visibility, they based their judgments on the relative size of the standard and comparison buildings, which did not vary. Air crew members in both experiments seemed to be more concerned with estimating accurately and ignoring changes in stimulus parameters, either for motivational reasons or from greater experience. In both experiments ACM showed a wider variability of response in the first sequence, and greater dependence upon the APF or texture conditions. In the second sequence, there was no effect of APF in the first experiment, and there was no obvious effect of texture size in the second experiment. Comparing the results for the two sequences. it is apparent that ACM are not giving perceived distances in the second sequence, but are relying upon the identification of the buildings by size or position.

The results of Gilinsky (1951) and others revealed that perceived distances are foreshortened. That is, as true distance increases, perceived distance also increases, but at a slower rate. Thus, an actual distance of 100 yds. may be seen as 40 yds. A subject may, however, report the object as being 100 yds. distant if he has learned that objects that appear to be 40 yds. away are, in fact, 100 yds. away.

The results of our experiments do not support the results of Gilinsky (1951). In our experiments most errors were over-estimates of the true distances. Students, particularly in the first experiment, tended to grossly over-estimate the distances. Several students mentioned that they had no idea of how far one could see at the given altitude, and, therefore, the entire scale for several subjects was much too large. ACM had a better idea of how far one can see, under given conditions, but each apparently assumed different conditions, which biased their estimates.

In the second experiment over-estimates by ACM were about the same as in the first experiment (compare Figures 9 and 17); over-estimates by the students were greatly reduced, presumably due to the addition of the textured background. The reason for the consistent over-estimation of distances is unclear. If the ACM are reporting estimated distances, it may be that their correction factor is inaccurate. On the other hand, the buildings may actually appear to be farther away than they are. There are several variables that might be involved.

<u>Height in the Field</u>. It is possible that the altitude of the observation point played an important role. Gilinsky (1951) assumed that the distance estimates in her experiment were based on relative size cues alone. In our experiment, the observation point was 1000 ft. above the ground. Thus, the array of buildings was spread farther on a vertical scale than they would have been had the observation point been at ground level. In our case, position, or height of the stimulus in the field, may have been an important and somewhat distorted cue for subjects unused to the altitude. Only 22 of the 40 students had even been in an airplane.

The work of Epstein (1966) suggests that, in the absence of relative size cues, the effectiveness of height in the field as a cue to depth depends upon the background upon which the stimulus is shown. With no background, two spots presented at different heights in the frontoparallel plane are not seen in depth. With a florescent outline drawn in linear perspective, an illusion of depth is created and with a "textured" grid pattern background even longer estimates of depth are produced, for a given vertical separation. Thus, height in the field can be used as a cue to depth, but not, apparently, in the absence of linear perspective. Unfortunately, Epstein (1966) used vertical separation in the frontoparallel plane, and there is no way to assess whether or not the estimated horizontal separations were "accurate." That is, whether two discs of equal relative size, separated on the horizontal plane so as to produce the vertical separations equal to those used by Epstein, would produce depth estimations similar to those given by Epstein's

subjects. Without such a comparison it is not possible to determine whether the height of the observation point can distort perception of distance.

Sequence and Scaling Effects. Stimulus sequence appears to have been important in both experiments. In both experiments, the first few estimates in the first sequence were shorter than all subsequent estimates. Subjects appear to have some difficulty in "fitting in" all the buildings, given their initial estimates. Thus, estimates became longer during the first sequence. In the experiment on aerial perspective the estimates to the middle buildings were considerably influenced by the distance of the preceding building. For example, when a building at 4.3 mi. was preceded by one at 7.1 miles it was estimated as being closer than when it was preceded by a building at 1.6 miles. These sequence effects were less noticeable in the second experiment, due to the more careful randomization procedures.

It is not clear why estimates during the second sequence tended to be longer than those during the first sequence. As noted above, some subjects seemed to have difficulty in "fitting in" all of the buildings once a scale was established early in the first sequence. The rest period and second sequence may have given an opportunity to change the scale without a feeling of inconsistency. Subjects who asked if they could change the scale were reminded that the instructions were to tell the experimenter how far away the buildings appeared to be.

With regard to the question of scaling, it is important to note that all distances are over-estimated, indicating a problem of absolute scale, rather than relative size or position in the field. Two variables are relevant to this question: assumed size and the visual angle of the display.

Relative or Assumed Size. In both experiments all subjects were told the actual size and distance of the first or standard building. They were also given a reference for the length of the building: "about as long as a football field." From some air crew members' comments, however, we discovered that many of them were relating the displayed building to a particular building in their experience. Just as the ACM's in the previous experiment had used a particular air field as their reference for the aerial perspective condition, ACM's in the present experiment admitted that they tried to remember at what distance a particular building (e.g. one half of the Air Force Museum) looked about the size of the comparison building. Thus, assumed size played an important role in many ACM's judgments in addition to relative size. It is not known whether student observers also had particular buildings in mind in making their judgments.

There has been some controversy in the literature over the relative importance of assumed and relative size of objects in estimating distance (see Epstein, 1967 for a review). However, most of these experiments involved setting two stimuli to equal distances or equal sizes under restricted viewing conditions. Few experiments in the area of distance

perception involved determinations of absolute distance to a given object. Those that investigated absolute distance estimation (e.g. Gilinsky, 1951: Gibson, Bergman, & Purdy, 1955) found that subjects consistently under-estimated distances. These results have not been confirmed. It may be that the computer generated display, as we have used it, is unusual enough that "normal" responses are precluded. Considering some of the strategies used by the ACM, however, the visual angle of the display is surely an important factor.

Visual field size. The computer projects a field which is 60° vertically and 72° horizontally. Due to constraints imposed by the Advent Projection System, the observers sat 14 ft. from the projection screen, thereby reducing the visual angle of the display to 18°30' vertically and 22°30' horizontally. This represents a magnification of 0.375 in the horizontal dimension and 0.308 in the vertical. It is highly probable that this reduction caused some distortion in the perception of distance within the display. Roscoe (1975) performed several experiments involving magnification of image size, or a projection periscope, and discovered that a magnification of 1.25 produces the most veridical distance perception. As the vertical magnification in this experiment was 0.308, the magnification was different from the optimal by a factor of four.

Except for the students in the first experiment, the degree of over-estimation did not reach a factor of four (see Figures 4, 9, 17, and 23). However, the reduction in visual angle of the buildings from what they would be if actually located at .56 to 7.1 miles could cause the buildings to be perceived as being farther away, in spite of the presence of the standard. In future experiments it would seem advisable, given the flexibility of the computer generated display, to have a closer correspondence between the visual angle of the viewing screen and the visual angle depicted by the computer.

Perception or response bias. In the second experiment on texture it was noted that subjects responded as though the buildings were equally spaced on the horizontal plane from 1 to 8 miles (see Figures 17 and 23). There are three possible reasons for this result: a) that is the way subjects perceive it to be, b) that is what subjects assume it to be, or c) despite instructions to use miles or fractions of miles, whole numbers are "easier". All three reasons are probably involved to some extent. First, the closer buildings are fairly evenly spaced on the screen. Without some quick geometry, naive observers may not realize that equal vertical space does not mean equal horizontal space over ground. Second, there is a certain tendency for all subjects to employ strategies to do well. Given that the closer buildings may look equally spaced, the subjects may simply assume that all the buildings are equally spaced and respond on that basis. Third, the experimental session is long and not exciting. Despite the emphasis to estimate the distance to the nearest quarter mile, it is easier to use whole numbers. Perhaps telling subjects that all the buildings are not equally spaced is the only reliable way to avoid the last two problems. However, if the buildings do appear equally spaced, we are then biasing the results. It should be noted that the perceived or estimated spans between the buildings was much more variable in the first experiment than the second. In the absence of the

texture pattern it may have been more obvious that the buildings were not equally spaced.

Part of the over-estimation problem is surely due to the fact that those students or ACM who do over-estimate the distances do so by a greater amount than those who under-estimate. This fact tends to increase the mean estimate substantially. If future experiments continue to show this problem, it may be more appropriate to use the median than the mean as a measure of central tendency, in spite of the statistical problems involved.

It is possible that the addition of other cues within the display would reduce the over-estimation still further. Air crew members have indicated that roads and additional buildings provide cues for them in normal flying situations. Where such stimuli have been added for simulation purposes the results have been favorable. The addition of other cues also depends upon the ultimate use of the display. If the display is to be used to make landings in 0 visibility conditions, extremely accurate perception is desirable. However, if the display is to be used to give a pilot a feeling for what is out the window and is to be accompanied by a variety of instruments for precise altitude and attitude data, then the results of the two experiments we have conducted indicate that aerial perspective, a background texture that includes linear perspective cues, and accurate relative size cues are sufficient to produce a perception of distance within the display. For experienced pilots, relative size appears to be sufficient (see results of Experiment I - Aerial Perspective Factor), but they prefer more cues for a more realistic display. Many air crew members were not comfortable making absolute distance estimates. They felt that such estimates were not directly required in landing an aircraft and they were unused to thinking in terms of absolute distance to an object in numbers of miles. This discomfort may partially account for the over-estimates. If the task had been performance in a simulated runway landing, the pilots would probably have performed better than their estimates would indicate. Thus, the specific use of the display and the task of the user should be carefully considered in determining the type of information to be presented in a complex display of this type.

APPENDIX

To obtain the color of an object in normal fog General Electric uses the following formula:

$$C_o = FC + (1-F)\ G$$

where:

C_o = actual color (see below)

F = range factor = e^{-kd}

where: k = attenuation coefficient

d = slant range to object in feet at which object is 50% assigned color and 50% fog color.

C = assigned color of object with no fog

G = fog color

$$C = N_R R + N_G G + N_B B$$

R, G and B = maximum energy of 3 color systems

N_R, N_G, and N_B = fraction of each color required to produce assigned color.

For aerial Perspective factor the density of fog decreases with altitude. The specification of d includes the factor + 10h where h is the altitude of the viewing point. One specifies the distance to 50% object color and 50% fog color at 0 altitude (d') and the altitude (h) and the computer determines d, the slant range to an object that is 50% assigned color and 50% fog color.

REFERENCES

1. Braunstein, M. L., Motion and texture as sources of slant information. Journal of Experimental Psychology 1968, 78, 247-253.

2. Epstein, W., Perceived depth as a function of relative height under three background conditions. Journal of Experimental Psychology, 1966, 72, 335-338.

3. Epstein, W., Varieties of Perceptual Learning. McGraw-Hill, New York, 1967. Percept'al Conflict (See Schreiver & Kilpatrick).

4. Gibson, E.J., Bergman, R., and Purdy, J., Effect of prior training with a scale of distance on absolute and relative judgments of distance over ground. Journal of Experimental Psychology 1955, 50, 97-105.

5. Gibson, J. J., Perception of visual surfaces. American Journal of Psychology, 1950a, 63 (3), 367-384.

6. Gibson, J. J., The Perception of the Visual World, Houghton Mifflin, New York: 1950b.

7. Gilinsky, A. S., Perceived size and distance in visual space. American Journal of Psychology 1951, 64, 460-482.

8. Winer, B. J. Statistical Principles in Experimental Design. McGraw-Hill: New York, 1962.

9. Wohlwill, J. F., The perspective illusion: Perceived size and distance in fields varying in suggested depth in children and adults. Journal of Experimental Psychology, 1962, 64, 300-310. "random checkerboard" - spacing of elements to produce depth.